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A quarterly review designed to record the progress
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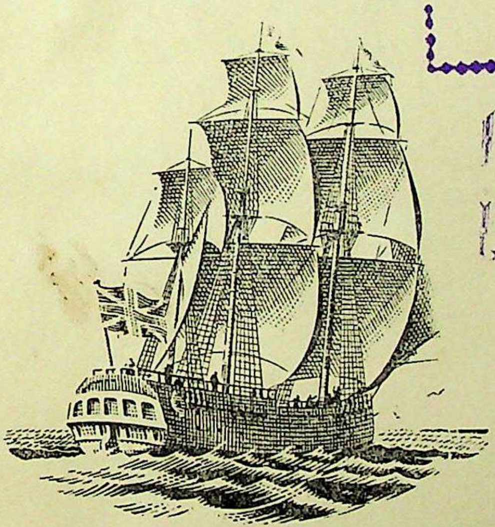

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E. N. da C. ANDRADE, D.Sc., Ph.D., F.R.S., has been Director in the Royal Institution of Great Britain and Director of the Davy Faraday Research Laboratory since 1st January, 1950. He was formerly Quain Professor of Physics in the University of London and is known for his fundamental work on the mechanical properties of solids and liquids.

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W. J. ARKELL, M.A., D.Sc., F.R.S., has held research fellowships at New College, Oxford (1933–40) and since 1947 at Trinity College, Cambridge. In 1944 he was awarded the Thompson Gold Medal of the United States National Academy of Sciences, and in 1949 the Lyell Medal of the Geological Society of London.

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WILSON BAKER, M.A., D.Sc., F.R.S., was appointed to the Chair of Organic Chemistry at the University of Bristol in 1945; he was formerly Fellow and Praelector in Chemistry at The Queen's College, Oxford. He is the author of many papers on a variety of organic chemical subjects, and has recently become particularly interested in non-benzenoid compounds of essentially aromatic type.

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H. GRAHAM CANNON, M.A., Sc.D., D.Sc., M.Sc., F.R.S., was appointed to the Chair of Zoology in the University of Sheffield in 1926, and in 1931 he was invited to the University of Manchester, where he has been ever since. He is a functional morphologist whose interests lie among the *Crustacea*.

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SIR JOHN COCKCROFT, C.B.E., M.A., Ph.D., Hon. LL.D. (Toronto), F.R.S., was appointed Director of the Royal Society Mond Laboratory at Cambridge in 1935. In 1944 he accepted the directorship of the Montreal Laboratory of the National Research Council of Canada, and became Director of the Chalk River Laboratories. In 1946 he became Director of the Atomic Energy Research Establishment at Harwell.

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JEAN ÉMILE COURTOIS was *Interne*, then *Chef de Service* in the hospitals of Paris, and is now professor (without chair) in the Paris Faculty of Pharmacy. Since 1930 he has worked with P. F. Fleury.

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C. A. CROMMELIN has been assistant, conservator, and vice-director of the Kamerlingh Onnes cryogenic laboratory. Until his recent retirement he was also Director of the National Museum for the History of Science in Leiden.

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R. DELABY, D.Sc., has been General Secretary of the International Union of Pure and Applied Chemistry since the end of 1945. Before this he was General Secretary of the Chemical Society of France from 1933 to 1940, and was its President in 1947.

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H. EPHRUSSI-TAYLOR, M.A., Ph.D., is working as *Chargé de Recherche* of the *Centre National de la Recherche Scientifique*, attached to the *Institut de Génétique* in Paris. Interested primarily in problems of heredity, she has centred her work on bacteria, with special reference to the transformation of pneumococci.

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DAVID S. EVANS, Ph.D., F.Inst.P., took up an appointment as Second Assistant at the Radcliffe Observatory, Pretoria, in 1948. During the war he was engaged at Oxford in research on physical problems relating to medicine.

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E. FAURÉ-FREMIET was appointed to the Chair of Comparative Embryology at the *Collège de France* in 1928. His principal researches have been on infusoria and ciliates, a field in which he has published many original papers.

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PAUL FÉLIX FLEURY has carried out research on oxidation by per-iodic acid, on laccase, on inositol, and on analytical biochemistry, and since 1942 has occupied the Chair of Biochemistry in the Paris Faculty of Pharmacy.

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SIR CYRIL (SANKEY) FOX, D.Sc., F.G.S., F.R.A.S.B., joined the Geological Survey of India in 1911 and became its Director in 1939. He is particularly interested in water-supply problems and economic geology.

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R. J. GAUTHERET, D.Sc., was appointed Professor of Plant Biology at the Sorbonne in 1942. His researches are chiefly concerned with plant tissue culture, a subject in which he was one of the first to achieve success.

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MYRON GORDON, B.S., M.S., Ph.D., has been geneticist of the New York Zoological Society since 1940, and since 1946 has also worked as principal investigator on the project "Genetic and Correlated Studies of Normal and Atypical Pigment Cell Growth" sponsored by the U.S. Public Health Service.

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JOHN HAMMOND, C.B.E., M.A., D.Sc., F.R.S., was appointed Reader in Agricultural Physiology, University of Cambridge, in 1943. He is a member of the editorial board of the *Journal of Agricultural Science* and the *British Journal of Nutrition.*

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GEORG KIRCHNER was in the service of the amber works at Königsberg and Palmnicken, East Prussia, from 1900 to 1944. The first scientific classification and arrangement of all finds of amber fossils were in his hands as manager of the concern dealing with the preparation and sale of raw amber.

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G. LAPAGE, M.A., M.D., is engaged in research on parasitology at Cambridge and was recently appointed to the staff of the new department of veterinary studies as Lecturer in Animal Pathology.

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W. H. MCCREA, M.A., B.Sc., Ph.D., F.R.S.E., has been Professor of Mathematics in the University of London (Royal Holloway College) since 1944. He was Secretary of the Royal Astronomical Society from 1946 to 1949, and is the author of papers on relativity and astrophysics as well as on other branches of mathematics.

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H. W. MELVILLE, Ph.D., D.Sc., F.R.S., F.R.I.C., was appointed to the Mason Chair of Chemistry in the University of Birmingham in 1948. Previously he had been in Aberdeen, where he established the school of high-polymer chemistry, with concurrent and continuing interest in the mechanism of chemical reactions.

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F. A. PANETH, Ph.D., F.R.S., is head of the chemistry department and Director of the Londonderry Laboratory for Radiochemistry at Durham University. He is also President of the Joint Commission on Standards, Units, and Constants of Radioactivity of the International Council of Scientific Unions.

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JAMES PATON, M.A., B.Sc., F.R.S.E., is interested in atmospheric optical phenomena, and is engaged in research on aurora and luminous night clouds. He lectures on thermodynamics at Edinburgh University, and is Scottish Secretary of the Royal Meteorological Society.

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H. M. POWELL, B.Sc., M.A., was appointed Reader in Chemical Crystallography at Oxford in 1944, in charge of a reorganized department devoted to that subject. His most recent investigations have been on stable molecular compounds formed by the inert gases.

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PRINGSHEIM, E. G. The cultivation of algae 138

E. G. PRINGSHEIM, D.Phil., has published papers on plant physiology, and on the taxonomy and biology of flagellates. From 1923 to 1938 he was head of the department of plant physiology in the German University of Prague; he is now curator of the culture collection of algae and protozoa at the Botany School, Cambridge.

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E. G. RICHARDSON, B.A., Ph.D., D.Sc., is Reader in Physics at King's College, Newcastle-upon-Tyne (University of Durham). He has specialized in the physics of sound, and has written many books and papers on this subject.

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ERWIN SCHRÖDINGER, Dr.Phil., M.A., Sc.D., For.Mem.R.S., was awarded the Nobel Prize in 1933 for "Wave Mechanics," his main contribution to physics. He is at present at the Dublin Institute for Advanced Studies, and in this article he summarizes, for the first time for many years, his attitude towards current general views in physics.

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ANNE STEPHENSON has, since her marriage with Professor T. A. Stephenson in 1922, acted as her husband's assistant on several ecological surveys, and has published joint ecological papers with him.

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T. A. STEPHENSON, D.Sc., is Professor of Zoology in University College, Aberystwyth. He was in charge of the section of the Great Barrier Reef Expedition (1928–9) which studied shore ecology, and has published many papers on this subject.

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ERNEST TILLOTSON, M.Sc., F.G.S., F.R.A.S., is honorary secretary of the British Association Seismological Committee, and a member of the American Geophysical Union. He has published a number of papers on seismology and geophysics.

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S. TOLANSKY, Ph.D., D.I.C., D.Sc., F.R.A.S., was appointed to the Chair of Physics at the Royal Holloway College, London University, in 1947. Formerly (1939–45) he was a member of the staff of the physics department at Manchester University. For the past eight years he has developed new interferometric techniques for the study of surfaces, and for this work was awarded the Charles Vernon Boys prize by the Physical Society of London.

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K. R. WEBB, B.Sc., Ph.D., A.R.I.C., has been Lecturer in Chemistry, University College, Southampton, since 1939. He has published work on inorganic and physical chemistry, as well as on the history of chemistry, and has been local representative of The Chemical Society for the Southampton area since 1946.

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H. J. J. WINTER, M.Sc., Ph.D., A.Inst.P., F.R.Asiat.S., is Lecturer in Education (scientific method and history of science) in the University College of the South West, Exeter.

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Science, history, and civilization

The vast expansion of science in the present century, with its accompaniment of an ever-increasing specialization, has led many scientists to develop a growing interest in the history of science. It is as though the constantly narrowing field of their own work has led them to seek mental refreshment in a study of the vast and variegated tapestry of history to which they are adding their individual fragments. This awakening to the value of historical science as a corrective of scientific specialization has shown itself in the foundation in many countries of societies and journals devoted to such studies; moreover, the movement has received the seal of academic recognition. As a consequence, there is now a widespread opinion that historical science offers one of the best ways of opening up a wider horizon for followers of the arts no less than for those of the sciences, providing them in so doing with a common intellectual interest and meeting-ground. In both fields, indeed, the history of science becomes a dominant theme in the history of civilization. The publication of a work on historical science by a professional historian is therefore a significant happening that calls for something more than a cursory reference in journals devoted to science.

The University of Cambridge has taken a noteworthy part in promoting the study of historical science. In 1937, the general board approved a series of weekly lectures on the history of science, delivered throughout the session by experts on various themes, and open without fee to all members of the university. In 1944, the movement was greatly stimulated by the presentation to the university of the Whipple collection of rare scientific instruments and books, of great historical value. At the inaugural ceremony, Sir Henry Dale, then President of the Royal Society, emphasized the importance of the study of the history of science, both by scientists who needed to appreciate the human side of their work, and also by students of classics, history, and theology. Similar activities have been fostered in other academic centres, both in Britain and abroad. For a recent undertaking at Cambridge, the history of science committee invited the professor of modern history in the university to deliver a course of a dozen lectures on the history of scientific activity in modern times, viewed as a continuous process of development. This task he fulfilled with distinction.

In his admirable lectures, recently published,[1] Professor Butterfield stresses above all the part played by the sciences in the evolution of western civilization; his exposition makes it clear that the history of science has contributed many of the threads woven into the unbroken web of human history. Taking the broad view of the historian, he states his opinion that the scientific revolution, resulting in the eclipse of scholastic philosophy and in the destruction of Aristotelian physics, 'outshines everything since the rise of Christianity and reduces the Renaissance and Reformation to the rank of mere episodes, mere internal displacements, within the system of medieval Christendom.' Indeed, he considers that this remoulding of scientific thought 'looms so large as the real origin both of the modern world and of the modern mentality that our customary periodization of European history has become an anachronism and an encumbrance.' This outspoken opinion, foreshadowing a devaluation of certain historical currencies, will find ready acceptance among historians of science.

The dawn of the seventeenth century saw also the dawn of modern science, but the ultimate roots of the scientific revolution of that era strike back a long way, even far beyond classical Greece. The literary transmission to the western world of the scientific knowledge of the ancient civilizations, reaching its culmination at the time of the Renaissance, brought about a saving of centuries of effort: 'in the middle ages men found themselves endowed with an explanation of the physical universe and the workings of nature which had fallen upon them out of the blue . . . and they were infinitely more the slaves of that intellectual system than if they had actually invented it themselves.'

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[1] H. Butterfield, *The Origins of Modern Science*, 1300–1800, Pp. x + 217. G. Bell and Sons Limited, London. 1949. 10s. 6d. net.

The key opening the gates of the scientific revolution is to be found in the law of inertia, the recognition of which ultimately led to the abandonment of an imagined universe actuated by invisible hands in favour of a new model having an automatic mechanism of a clockwork type; but nearly a century and a half had elapsed after Copernicus had published his great work, *De Revolutionibus Orbium* (1543), before Newton was able to effect his grand synthesis of the underlying dynamical and gravitational problems in his *Principia* (1687). This correlation of mechanics and astronomy, of motion in the earth and in the skies, lies at the very core of the scientific revolution of the seventeenth century. Similarly, in the realm of biology, Vesalius' *De Fabrica* (1543), the foundation of anatomy, published in the same year as the master-work of Copernicus, was followed in due course by Harvey's revolutionary thesis, *De motu cordis* (1628). A new era had opened in the study of living organisms.

There was a celebrated Frenchman who took care that the new views should become generally known. Fontenelle, nephew of Corneille, and in Voltaire's opinion the most universal genius of his day, became an early and successful popularizer of science. Living to within a month of his centenary (1657–1757), this remarkable man spanned the passage from the scientific revolution of the seventeenth century to the 'age of reason' of the eighteenth. Professor Butterfield describes his *Entretiens sur la pluralité des mondes* (1686) as 'the first work in France which made the discoveries of science clear, intelligible, and amusing to the general reading public.' Science stands urgently in need of such expositors at the present day, for it has never been so important as it is now for the ordinary man to know what science is doing, and to understand the implications of the new knowledge and the powers that it brings.

It is a striking feature of the history of science that the scientific revolution of the seventeenth century did not reach chemistry. It is often held that the misleading theory of phlogiston was mainly responsible for the postponement of the chemical revolution until late in the eighteenth century, but, as a recent writer has emphasized, the delay was due rather to lack of knowledge of the different kinds of gases and of the technique of handling them, and to the rudimentary views that were held at that time concerning chemical change. There were 'no clues to the composition of air, fixed air, or water; and, while air is the food of fire, fixed air and water are the products of combustion of all organic materials.'[1] The work of Black, Scheele, Priestley, and Cavendish, in the second half of the eighteenth century, inaugurated a new era by preparing the way for a recognition of the chemical nature of air and water. Then, as so often in the history of science, a point was reached at which all the necessary data had been collected to enable a tremendous step forward to be made.

That great historian of science, George Sarton, has recently written: 'It is true that most men of letters, and, I am sorry to add, not a few scientists, know science only by its material achievements, but ignore its spirit and see neither its internal beauty nor the beauty it extracts continually from the bosom of nature. . . . A true humanist must know the life of science as he knows the life of art and the life of religion.'[2] Professor Butterfield has shown himself to be a true humanist.

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[1] J. Read, *Humour and Humanism in Chemistry* (London, 1947).

[2] G. Sarton, *The Life of Science; Essays in the History of Civilization* (New York, 1948).

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The steady-state theory of the expanding universe

W. H. McCREA

According to the steady-state theory, the creation of matter is proceeding at the same rate now as in the past. The present article reviews the difficulties in previous cosmologies which the new theory appears to overcome, and indicates its promise of success in explaining certain general features of the universe, such as the formation of galaxies and systems of galaxies.

1. The steady-state theory of the expanding universe was propounded by H. Bondi and T. Gold [1] in 1948. Their suggestion is that the creation of matter is a continuing process operating at the same statistical rate at all epochs, a statistically constant density being preserved by the dispersal of matter known as the expansion of the universe.

It is too soon to claim that any crucial consequence of this hypothesis is definitely established by available observational data. It does, however, appear to overcome serious difficulties encountered by previous theories when confronted with these data. It promises also to afford a satisfactory account of the formation of galaxies and systems of galaxies, a type of problem about which the previous theories have little information to offer.

THE EXPANDING UNIVERSE

2. *Cosmological principles*. Theories of the universe, in the main, deal in the first instance with models in which all the contents are regarded as 'smoothed out': the concentrations of matter into stars, galaxies, etc., in the actual universe are replaced by a continuous distribution of 'fluid' in the model, the motions of these bodies being represented by the hydrodynamical behaviour of the fluid. The distribution of radiation is treated similarly. The models are also required to be homogeneous and isotropic (uniform). Homogeneity implies that a (fundamental) observer A, moving with the fluid, forms, at any instant in his experience, the same picture of the universe as does another such observer B anywhere else in the universe at some instant in B's experience. Unless the universe is in a steady state, this implies the existence of cosmic time, a particular instant in cosmic time being that at which all fundamental observers see the same picture. What is homogeneous is in fact the whole of space at any instant of cosmic time. Isotropy means that every fundamental observer sees the universe as radially symmetric about himself.

The hypothesis of homogeneity is also called the cosmological principle (CP), but, since it refers to space only and not to time, we may call it the restricted CP. A universe that is homogeneous in time, i.e. in a steady state, as well as homogeneous in space, is said by Bondi and Gold to satisfy the perfect CP. It follows, not that nothing happens in such a universe, but that the same things are happening all the time.

As regards the actual universe, surveys of the sample accessible to observation are considered to show that it is in fact spatially uniform, when regarded statistically on a large enough scale. Whether it is in a statistically steady state is the major problem before us. The solution cannot be had directly from observation; as we shall see, the interval required for a significant statistical test would be of the order of 10^9 years. The only hope of a solution lies in the comparison with observation of various predictions based on the possible alternative hypotheses.

3. *Model universes* [2]. The first theoretical model of the universe was that proposed by Einstein in 1917. At that time it seems to have been taken for granted that the universe as a whole must be in a steady state, at any rate mechanically, which is all that concerns a purely gravitational theory. Einstein noted that his original gravitational equations admitted no static homogeneous solution. A static solution was possible only for the equations modified by the so-called 'cosmical terms' having as coefficient the mysterious cosmical constant λ. The model which then resulted is well known, being that which led to discussions of 'finite but unbounded space' and 'seeing round the universe.'

The only other uniform steady-state solution is that discovered about the same time by de Sitter. This is a non-static solution of Einstein's modified equations. But, since those equations require the conservation of matter, the matter in the universe as a whole can be in motion, and yet have a density that does not vary with time, only if the density is zero. So de Sitter's is an empty universe. As a model it could, however, be regarded as a possibly instructive limiting case. As such it was of great significance, for it first served to predict the recession of the galaxies with speeds proportional to their distances.

Non-steady uniform models were then studied, first by Friedmann (1922) and Lemaître (1927). The immediate result of their work was that it enabled Eddington to deduce that Einstein's static universe is unstable in regard to sorts of disturbance which certainly occur in the actual universe. Consequently the universe is not in a static state. Its mean density is not zero, and so neither is it in the only other (de Sitter) possible steady state allowed by relativity theory.

Relativists, therefore, studied exhaustively all classes of non-steady uniform solutions of Einstein's equations, both with and without the cosmical terms. All solutions predicted the phenomenon of mutual recession of fundamental observers with speed proportional to distance (at any rate to a first approximation), i.e. the expansion of the universe.[1]

While these theoretical conclusions were being reached, observational evidence for the recession of the galaxies was also being amassed, and Hubble's law, that the speed of recession is proportional to the distance, was emerging as an empirical result. So the conclusions were hailed as a triumph of the relativity theory.

An element almost of disillusionment was then introduced by Milne's suggestion [3] that the recession may be ultimately no different from the purely kinematic phenomenon of the dispersal of, say, a cloud of gas in space or of a handful of beads spilled on the ground. It can be shown, however, that this actually is the phenomenon studied in the relativity treatment, subject to the mutual gravitation of the parts of the dispersing material and to the uniformity condition.

Milne himself followed up his suggestion by developing his system of kinematic relativity [4]. As concerns models of the universe, this theory yields analogues of certain of those given by general relativity. It thereby provides an alternative treatment of the same physical situations.

The nature of these situations was further clarified when Milne [5] discovered the Newtonian analogue in one case, and Milne and McCrea [6] proceeded to show that Newtonian analogues exist for all the relativity models.

4. *Physical interpretation.* Some explanation of this last result is needed. Consider ordinary Newtonian space and time (t). Let O be any fundamental observer, R any point of space such that $OR = \mathbf{r}$, ρ the density of matter at R, and $\mathbf{v}$ its velocity. As is easily shown, the restricted CP requires that $\mathbf{v}$ be a scalar multiple of $\mathbf{r}$, say $\mathbf{v} = V\mathbf{r}$, and that ρ and V be independent of $\mathbf{r}$.

O certainly sees this 'universe' as spherically symmetrical about himself. If he then makes a straightforward application of Newtonian gravitation for a spherically symmetrical distribution of mass, and uses also the equation of conservation of matter, he obtains differential equations for ρ and V as functions of t.

The equation for V is not only analogous to, but also formally identical with, the corresponding equation for the relativity models with $\lambda = 0$. The theories differ only in 'geometrical' aspects. The three types of model arising in the relativity treatment are then revealed as those that any observer O would describe by saying that the material at distance r has more than, the same as, or less than the Newtonian 'velocity of escape' from that within distance r of himself.

Finally, the relativity equations with $\lambda \neq 0$ are found to be reproduced by the Newtonian model if, in addition to Newtonian gravitation, O assumes the existence of a force of 'cosmical repulsion' $\frac{1}{3}c^2\lambda\mathbf{r}$ (where c is the velocity of light and the coefficient $\frac{1}{3}c^2$ is introduced merely to match the relativity practice) [7]. It can be shown, moreover, that a term of this form is the only modification of Newtonian gravitation that can preserve conformity to the restricted CP.

Thus we know in easily appreciated terms the physical situation represented by any particular model, and that the physical phenomena are essentially the same whether the model is provided by general relativity, kinematic relativity, or Newtonian theory (which we shall call the 'dative' theories). It turns out, further, that the predicted observable characteristics of any model and its analogues in the different theories differ only in the second or higher orders as between one theory and another. This is embarrassing if we want to decide observationally between the relative merits of the theories, but it has the advantage that comparison with observation is not too much affected by mathematical differences between the treatments. If we encounter serious difficulties in interpreting the observations according to any one of the theories, such difficulties are almost certainly owing to inadequacies in the physical concepts, and are not to be overcome merely by replacing one mathematical treatment of those concepts by another.

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[1] Einstein's equations being reversible in time, any expanding solution gives also a contracting one by simply reversing the sign of the time-variable, but the latter need not be considered here.

5. *Comparison with observation.* Hubble [8] has thoroughly investigated the fitting of a relativistic model to the observational data. He finds the model that gives the best fit (subject to uncertainties in the reduction of the observations) to be highly unplausible on general grounds.

So impressed was Hubble by the impossibility of obtaining satisfactory quantitative agreement that he felt compelled to question the basic interpretation of the spectral shifts of the galaxies as velocity-shifts. But this solution of the difficulty is not readily acceptable, because no other interpretation is forthcoming[1] and also because the usual interpretation gives qualitatively the effect predicted by all the theories; it would be strange if the interpretation were then only partially applicable.

6. *Further difficulties.* Accepting the usual interpretation of the spectral shifts, Hubble's law is (to a sufficient approximation):

Speed of recession of a galaxy

$$= 1{\cdot}8 \times 10^{-17} \text{ cm/sec} \times \text{distance in cm} \quad .. \quad (1)$$

Therefore, if the galaxy has moved with uniform velocity, its distance was zero $(1{\cdot}8 \times 10^{-17})^{-1}$ sec, or about $1{\cdot}8 \times 10^9$ years ago, whatever its present distance.

This is the crudest possible estimate of the age of the universe. Every model of the sort already discussed leads, however, to approximately the same inference: that about 2×10^9 years ago all the matter in the universe was closely packed together (or else was then in the state of an Einstein static universe in which no previous evolutionary process had occurred).

Now the age of the oldest rocks on the Earth is known to be itself about 2×10^9 years. Until recently, the view was that all the stages in the evolution of the Galaxy, before that when the Earth was formed, could have been rushed through in much less than 10^9 years in the highly congested state in which the universe was inferred to be at the epochs concerned. So it was not found strange that the age of the Earth and that of the whole universe should be the same to a first approximation. Indeed, this and certain somewhat similar results were taken as generally favourable to the inferred age of the universe.

According to recent ideas concerning stellar evolution, on the other hand, the ages of the oldest stars in the Galaxy are estimated to be about 5×10^9 years. We are reverting, in fact, to the common-sense view that the Earth is considerably younger than a good many stars. The numbers quoted happen to be ones that are not susceptible to much revision within the framework of the theories concerned. So we have to conclude that the ordinary theory of the expanding universe fails to provide sufficient time for the evolution of its contents.

Other difficulties are metaphysical. The first is that the dative theories admit a variety of theoretically possible models of the universe. But, in the case of the entire universe, there is no sense in which any but one system is physically possible: a wholly satisfactory theory ought to yield only a unique model (granted that any theory of a unique system is conceivable).

In the second place, as emphasized by Bondi and Gold, physical laws are formulated on the assumption that the circumstances to which they apply are reproducible to an unlimited extent. This can hold good in a changing universe only if the 'laboratory' where the required circumstances are considered to be reproduced may legitimately be regarded as isolated from the remainder of the universe. If we accept Mach's principle that the properties of any portion of the universe are determined by the contents of the whole universe, this last condition cannot be satisfied. On this view, the meaning of physical law in a changing universe thus presents grave difficulties. Such difficulties may need to be resolved. But we can at least see if the need ever arises: we must fully explore the possibility of a steady-state universe.

7. *Time-scales.* A conceivable escape from some of the difficulties we have mentioned is provided by Milne's use of two time-scales. In his development of kinematic relativity he is led to employ an alternative measure τ proportional to the logarithm of the cosmic time t. So the 'epoch of creation $t = 0$ becomes on the τ-scale $\tau = -\infty$.' He [10] ultimately concludes, 'It thus appears that the paradox into which contemporary physics is led in discussing the age of the universe . . . is due to confusion of the two

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[1] Reference should, however, be made to Milne's views on this problem [9].

scales of time. . . . Statements involving Newtonian mechanics, or Newtonian gravitation, are usually made in terms of the τ-scale. Statements involving . . . photons, or the electromagnetic theory of Maxwell, involve the t-scale.'

The notion of two time-scales occurs also in Dirac's [11] approach to the same problems, but his transformation differs from Milne's.

It thus appears that the dative theories are unacceptable without some such treatment of the time-variable. But hitherto the notion has gained little general favour. Once again, we want to see first if the need for it really does arise.

COSMOLOGY AND CREATION

8. *Creation.* All previous theories assume the conservation of matter: they treat matter as 'given'[1] and avoid any consideration of its creation. As Hoyle [12] remarks, this is permissible provided all matter was created in the remote past, but not if its creation is a continuing process.

The question whether matter is being created at the present time is independent of cosmological theory. But, if creation is in progress, the rate must be so small as to offer no prospect of observing the process directly. It could be studied only in relation to the large-scale behaviour of the universe.

What has been said about the dative theories leaves little hope that their apparent inadequacies can be remedied by any modified treatment of space, time, and gravitation. That being so, their inadequacy must lie in their treatment of matter.[2] But all they assume about matter itself is that it is conserved. So there is a presumption that this postulate is invalid. Also, any fresh investigation of the possibility of a steady-state universe is in fact the investigation of the effect of abandoning this postulate. Otherwise the steady state would be incompatible with the 'expansion.' Thus the effect of all the foregoing discussion is that the possibility of continuing creation must now be considered.

The possibility has received some earlier consideration. In a well-known passage, Jeans [13] conjectured that the centres of galaxies might be places where matter is 'poured into our universe.' In a preliminary version [14] of his 'new basis for cosmology,' Dirac inferred a rate of creation of protons and electrons proportional to t. But he later [11] recast his formulation so as to be consistent with the conservation of matter. At the same time he remarked that 'there is no experimental justification for this assumption' of conservation: he regarded 'a spontaneous creation . . . of matter . . . as not to be worth considering, unless a definite need for it should appear.' Bondi and Gold [1] and Hoyle [15] have stated a strong case for this need, and have been the first to relate the possibility to general problems of astrophysics and cosmology.[3]

9. *Creation process.* In constructing a theoretical model universe in which matter is continually being created, corresponding to the earlier dative models, the creation process, like all the other features, is treated as smoothed out in space and time. The model will thus yield conclusions that are independent of details of the creation process.

It is convenient, however, at this stage to state what process is actually envisaged. The authors quoted suggest that:

(*a*) It is the spontaneous creation of *hydrogen atoms* (or of protons and electrons, or neutrons, the first resultant of which would be atomic hydrogen). This is because hydrogen is the simplest and most abundant element, and astrophysical evidence indicates that all other elements have been synthesized from hydrogen.

(*b*) It is random in space, being independent (to a first approximation at least) of local physical conditions. Thus it is not associated with existing concentrations of matter. This is because processes of condensation and accretion appear to be more fundamental in astrophysics than the reverse processes.

(*c*) Newly created matter is statistically at rest relative to its cosmical neighbourhood.

As described by any observer it must therefore possess the characteristic velocity of recession which he associates with its position.

One may remark that there can be no causal treatment in a physical sense of true creation. This is almost a matter of definition. If the creation of matter is caused, as is conceivable, by existing physical conditions, then the true creation is of those conditions, and we should not try to give a physical theory of that creation. But we are here regarding the creation of matter as itself spontaneous, i.e. as something 'given' and not to be treated causally. We can assume that the immediate results of the creation process may be treated by probability methods, as are other spontaneous processes in atomic physics.

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[1] Hence my venturing to term them 'dative' theories.

[2] This expresses the situation in ordinary physical terms. In the language of relativity theory, we should say that the existing field-theory is in need of revision, but we could still say that this is particularly so in regard to the conservation properties deducible from the field-theory.

[3] P. Jordan has independently concluded that it is necessary to postulate the continuing creation of matter. An account [19] of his ideas, more accessible than that in which they were originally published, has appeared since the present article was written. Jordan's formulation is, however, in less conformity with other current astrophysical theories than that of the authors mentioned above.

10. *Model universe with creation.* In order to have a definite model on which to base further discussion we provisionally accept the perfect CP. Also, we shall use Newtonian space and time, since the earlier work serves to show that this should be adequate to yield first approximations to observable relations.

The first paragraph of section 4 still holds good, since the restricted CP is included in the perfect CP. But the latter further requires the universe to be in a steady state; so ρ, V must now also be independent of t, i.e. they are universal constants (and we shall take them to be positive).

The rate at which matter is flowing out of the sphere of radius $r = |\mathbf{r}|$ is $4\pi r^3 \rho V$ per unit time. But the perfect CP requires the mass in this sphere to remain steady, i.e. it requires matter to be created at the rate μ, say, where

$$\mu = 4\pi r^3 \rho V / \tfrac{4}{3}\pi r^3$$
$$= 3\rho V \text{ per unit volume per unit time} \quad .. \quad (2)$$

Matter receding from O with a velocity exceeding the velocity of light c would be unobservable to O. Hence O would place the boundary of his theoretically observable universe at the distance R, where the speed of recession is c, i.e.:

$$R = c/V \quad .. \quad .. \quad (3)$$

The mass M inside this distance is

$$M = \tfrac{4}{3}\pi\rho R^3 = \tfrac{4}{3}\pi\rho(c/V)^3 \quad .. \quad (4)$$

Any fundamental observer must therefore describe the universe as having radius R and mass M. Despite the continued creation of matter, it is to be noted that the mass of the universe is conserved.

The acceleration of a particle with velocity $V\mathbf{r}$ is $V^2\mathbf{r}$. The observer O, using Newtonian gravitation for a spherically symmetrical distribution of density ρ, assigns an acceleration due to gravity $-\tfrac{4}{3}\pi\gamma\rho\mathbf{r}$, where γ is the gravitation constant. Therefore he must postulate a repulsive force per unit mass of amount $\tfrac{1}{3}c^2\lambda\mathbf{r}$ in the notation of section 4, where

$$\lambda = 3(V/c)^2 + 4\pi\gamma\rho/c^2 \quad .. \quad (5)$$

Thus the model requires a non-zero cosmical constant, at any rate for this type of mechanical description. So this description does not yield a relation between ρ and V alone.

We then notice that O would evaluate the Newtonian velocity of escape from the material within distance r as $\{2(\tfrac{4}{3}\pi\gamma\rho r^3)/r\}^{\frac{1}{2}}$. Since the material at this distance has speed Vr, he would say that the material at all distances has the velocity of escape if

$$\rho = 3V^2/8\pi\gamma \quad .. \quad .. \quad (6)$$

TABLE I

Constants of the model universe

Recession constant	V	$1{\cdot}8 \times 10^{-17}$ sec^{-1}	$V\mathcal{T} = b\mathcal{N}^{-1}$
	b	$0{\cdot}38$	
Density	$\rho = \dfrac{3}{8\pi}\dfrac{V^2}{\gamma}$	$5{\cdot}8 \times 10^{-28}$ g cm^{-3}	$\rho\dfrac{\mathcal{L}^3}{\mathcal{M}} = \dfrac{3b^2}{8\pi}\mathcal{N}^{-1}$
Creation rate	$\mu = \dfrac{9}{8\pi}\dfrac{V^3}{\gamma}$	$3{\cdot}1 \times 10^{-44}$ g cm^{-3} sec^{-1}	$\mu\dfrac{\mathcal{L}^3\mathcal{T}}{\mathcal{M}} = \dfrac{9b^3}{8\pi}\mathcal{N}^{-2}$
Cosmical constant	$\lambda = \dfrac{9}{2}\dfrac{V^2}{c^2}$	$1{\cdot}6 \times 10^{-54}$ cm^{-2}	$\lambda\mathcal{L}^2 = \dfrac{9}{2}b^2\mathcal{N}^{-2}$
Radius of observable universe ..	$R = \dfrac{c}{V}$	$1{\cdot}7 \times 10^{27}$ cm	$\dfrac{R}{\mathcal{L}} = \dfrac{1}{b}\mathcal{N}$
Mass of observable universe	$M = \dfrac{1}{2}\dfrac{c^3}{\gamma V}$	$1{\cdot}1 \times 10^{55}$ g	$\dfrac{M}{\mathcal{M}} = \dfrac{1}{2b}\mathcal{N}^2$

$\mathcal{L}$, $\mathcal{M}$, $\mathcal{N}$, and $\mathcal{T}$ refer to Dirac units; see table II.

Relation (6) is a consequence of Hoyle's theory (section 12), but, as he remarks, we might expect something like it on general grounds. For, were the velocity less than the velocity of escape, then on ordinary gravitational ideas we should not expect the recession to be maintained. On the other hand, were the velocity much greater, we should not expect the formation of condensations (galaxies) (section 13). Also the numerical value of ρ given by (6) is plausible on observational grounds [16]. So, although (6) is not a necessary consequence of the model, we shall adopt it here.

Numerical results are given in table I. Column 1 gives also the expressions for the other constants in terms of V, obtained by using (6) in (2), (4), and (5).

11. *Discussion.* The only empirical value is that of V from (1). We have already quoted Hoyle as to the plausibility of the value of ρ. As regards the value of μ, we may remark that it corresponds to the creation of about 500 hydrogen atoms per cubic kilometre per year, showing how impossible it would be to observe directly.

There is one interesting possibility of gaining general confirmation of the values found. Dirac has proposed as a principle of cosmology: 'Any two very large dimensionless numbers occurring in Nature are connected by a simple mathematical relation in which the coefficients are of order of magnitude unity.' He infers that, if N is any such number, then any other is to a first approximation a small integral power of N multiplied by a factor of order unity. He applies the principle to a different model, but we can see what it gives in our case.

Following Dirac, the relevant numbers are obtained by expressing the characteristics of the universe in physical units: those he selects are shown in table II. The number N which he uses for a standard of comparison is the ratio of the electrical to the gravitational force between a proton and an electron.

It has several times been remarked that the recession constant V multiplied by the time-unit used by Dirac gives a dimensionless number of the order N^{-1}. If we write this product as bN^{-1}, then the remaining constants of our model yield the numbers in table I, column 3. The coefficients are of what Dirac regards as 'order of magnitude unity' in the context. So we can claim that the model conforms to Dirac's principle. Therefore, in so far as we accept the principle, we can take it as favourable to the steady-state hypothesis.[1]

This conformity to the principle also indicates that the characteristics of the universe are closely related to fundamental atomic constants. This is what we should expect if the behaviour of the universe is determined by the creation process, i.e. an atomic process [17].

Finally, it is important to note that though the model gives an infinitely old universe in a steady state, it automatically escapes the conclusion that such a universe must have attained thermodynamic equilibrium. The maintenance of the one-way process of creation ensures, in fact, that it is not in thermodynamic equilibrium. This is in qualitative agreement with observation.

To sum up, we have a model that, as well as can be judged, reproduces the existing general state of the universe, possesses characteristics conforming to Dirac's requirements, and, having maintained the same state for an infinite time, should present no difficulty of inadequate time for the evolution of its contents.

12. *Field theory.* This model gives only a preliminary survey of what a coherent theory incorporating the new concepts is expected to produce. Hoyle [12, 15] has given tentative formulations of such a

TABLE II

'Dirac units'

Time	$\mathcal{T}$	$\frac{e^2}{mc^3}$	$\gamma\frac{\mathcal{M}N}{c^3}$	0·94 × 10^{-23} sec
Distance	$\mathcal{L}$	$\frac{e^2}{mc^2}$	$\gamma\frac{\mathcal{M}N}{c^2}$	2·8 × 10^{-13} cm
Mass	$\mathcal{M}$	$\mathcal{M}$	$\mathcal{M}$	1·7 × 10^{-24} g
Dimensionless number ..	N	$\frac{e^2}{m\mathcal{M}\gamma}$	N	2·3 × 10^{39}

e, m = electronic charge, mass; $\mathcal{M}$ = proton mass.

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[1] Admittedly, the characteristics of the model are so related by (2)–(6) that the satisfaction of Dirac's principle by some of them ensures it for the others. But this is partly the point at issue: we have not to introduce characteristics violating the principle.

theory by investigating field equations that resemble Einstein's as closely as possible without implying the conservation of matter. The model he derives has almost exactly the same characteristics as that described above. The only exception is that he does not require the cosmical constant λ; this is satisfactory, since we had to introduce λ only in order to give a purely Newtonian description of the phenomena.

Further, the treatments both of Hoyle and of Bondi and Gold yield for the metric of space-time, in the sense of representing light-tracks as null-geodesics, the metric of de Sitter's universe. But, since Einstein's equations are not assumed, there is no question of this being an empty universe. In fact, taking the density in accordance with their postulates, Bondi and Gold calculate with the aid of this metric the relative number of galaxies down to any given apparent magnitude. Comparison with observational surveys gives better agreement than that achieved by dative models with more disposable parameters.

EVOLUTION OF GALAXIES

13. *Galaxies.* We proceed to considerations beyond those associated with an entirely smoothed-out universe. All cosmological theories agree in regarding a galaxy as the primary type of concentration of matter. According to the new ideas, the number n of galaxies per unit volume of space is statistically constant. Newly created matter will in general tend to fall into the nearest galaxy. Thus any existing galaxy is continually growing by accretion. But the continual creation throughout space means that there is always an intergalactic distribution of matter. Now this intergalactic matter must exhibit fluctuations of density owing to the randomness of the creation process, irregularities in the gravitational field, etc. A sufficiently large fluctuation above the mean density in its neighbourhood must itself grow by accretion. Thus the mutual recession of existing galaxies is compensated by the birth of new ones, so maintaining the constancy of n. Any sufficiently large region of space must contain galaxies of all ages.

Consider again the model in section 10. Since the speed at distance r from O is Vr, the nebulae at distance r at time $t + T$ were at distance re^{-VT} at time t. Now let $n\,.f(a)$ be the number of galaxies per unit volume of age exceeding a. At time t the number of these within the sphere of radius r is $\frac{4}{3}\pi r^3 n\,.f(a)$. At time $t + T$ the number in the same sphere consists of those which at time t were of ages exceeding $a - T$ and were within the sphere of radius re^{-VT}, that is $\frac{4}{3}\pi r^3 ne^{-3VT}f(a-T)$.

But this must be the same as at t: hence

$$f(a) = e^{-3VT}f(a - T),$$

giving

$$f(a) = e^{-3Va} \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

since, by definition, $f(0) = 1$. Therefore the number of galaxies per unit volume of age a or more is ne^{-3Va}; the number of age between a and $a + da$ is $3n\,.\,Ve^{-3Va}da$; and the mean age is:

$$3V\int_0^\infty ae^{-3Va}da = 1/3V \doteqdot 6 \times 10^8 \text{ years.}$$

But there is the further question of how old a galaxy must be in order to be observed as a galaxy. We must conclude that the mean age of recognizable galaxies is appreciably greater than this estimate.[1] This is then a plausible result.

The present theory predicts a mixture of galaxies of various ages at all distances from an observer. On the other hand, the dative theories predict that the galaxies all have the same age t at the cosmic epoch t, being actually seen at an earlier age the farther they are from the observer. The difference between these predictions ought to make possible a discrimination between the theories when observational criteria of age have been determined.

A few further numerical considerations are interesting. We first recall the values:

Mean separation [18] of
neighbouring galaxies . . $2l = 1{\cdot}2 \times 10^{24}$ cm
Mass of Galaxy . . . . $M_0 = 5 \times 10^{44}$ g
Age of Galaxy . . . . $T_0 = 5 \times 10^9$ years.

The values of l, M_0 are those accepted from observational data; the value of T_0 has been quoted in section 6.

Using the values of ρ, μ in table I we find for the average mass M_1 within any sphere of radius l and the total mass M_2 created within the same sphere during time T_0:

$$M_1 = 5{\cdot}2 \times 10^{44} \text{ g.} \quad M_2 = 4{\cdot}4 \times 10^{45} \text{ g.}$$

Also the time T_1 of free fall from distance l, to a distance small compared with l, under the gravitational attraction of mass M_0 is:

$$T_1 = \tfrac{1}{2}\pi(l^3/2\gamma M_0)^{\frac{1}{2}} \doteqdot 2{\cdot}8 \times 10^9 \text{ years.} \quad (8)$$

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[1] If $2l$ is the mean distance between a galaxy and its nearest neighbour, then no new galaxy can be born, and remain distinct, much nearer to O's galaxy than distance l. Such a galaxy would in general recede to distance R in time $(1/V)\log_e(R/l) \doteqdot 1{\cdot}4 \times 10^{10}$ years, using the observed value $l \doteqdot 6 \times 10^{23}$ cm and V,R from table I. Consequently O can expect actually to see no galaxy older than this, unless it be his own or gravitationally bound to his own. This argument is due to Hoyle (*l.c.*). But (7) gives only one galaxy in over 1000 million older than this, so the argument has no effect on our conclusions.

Since M_0, M_1 are of the same order, we can conclude in a general way that a sphere of radius l about the Galaxy is not unreasonable as a 'sphere of influence.' This is confirmed by T_0, T_1 being of the same order, so that in fact the Galaxy during its lifetime could have captured material from within such a sphere. We have then to remember, of course, that the value of M_0 to be used in (8) would have been smaller in the past. So a considerable amount of the matter represented by M_2 would not have had time to fall into the Galaxy and some also would have receded from its sphere of influence. It is thus satisfactory to find that M_2 is considerably greater than M_0.

These elementary comparisons show that the times and masses involved are consistent with the idea of the Galaxy having grown by accretion.

Lastly, we may remark that the Galaxy is usually held to be something of a giant among galaxies in general, whose mean mass has been variously estimated at 1/10 to 1/100 of M_0. The figures already given show also that it is fairly old compared with the average. This association of mass and age gives qualitative support to the idea of growth by accretion.

If these ideas prove successful, the important quantities of which they should provide theoretical values include the mass of a galaxy of given age, the mean separation of galaxies, and the ratio of galactic to intergalactic matter.

14. *Clusters.* The majority of galaxies appear to be isolated individuals, but they may also occur in associations ranging from groups of several members (our Galaxy belonging to the 'local group' of about a dozen members) to clusters of several hundreds.

Bondi and Gold claim for the steady-state theory that it accounts naturally for this clustering tendency. Their explanation of the formation of clusters is basically the same as that we have given for the formation of the galaxies themselves. Just as a random distribution of atoms must tend to form condensations owing to the gravitational instability we have described, so a random distribution of galaxies must tend to form condensations, i.e. clusters, by the same process.

On these authors' view the operative time required for clustering to get under way is that for two galaxies to fall together from a separation of the order of $2l$. If both masses are about that of the Galaxy, this is about 6×10^9 years; if both are about one-tenth of that mass, it is about $1{\cdot}7 \times 10^{10}$ years. After such an interval, further galaxies may be captured at an increasing rate. Thus the times involved are just permissible on the views here stated concerning the ages of the galaxies themselves. In further support, Hoyle argues that our Galaxy, being a moderately old one, would be expected to be involved in a moderate degree of clustering, which is indeed the case.

REVIEW

15. In its present state, cosmological theory probably impresses the general theoretical physicist as a highly unsatisfactory subject. Though general relativity provides an elegant theory of the expanding universe, yet when cosmologists attempt to square its prediction with the observations, they resort either to unverified physical hypotheses (about spectral-shifts), or to mathematical devices such as the use of two time-scales and the treatment of universal 'constants' as being secularly variable. The creation hypothesis may appear to be just one more makeshift. In spite of the obvious need for further work, it can, however, be claimed to be of a different status.

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Life between tidemarks in North America

T. A. and ANNE STEPHENSON

Professor and Mrs Stephenson have been working for many years on a survey of intertidal ecology, and their studies have taken them not only round the shores of Britain but to Australia, South Africa, Mauritius, and North America. In the present article they describe some of the observations made on two recent expeditions to North America, in which they covered about 20,000 miles. Plates 2, 3, and 4 are from the authors' original paintings.

The rate of development of the different branches of biology is curiously uneven, and this is exemplified by our present knowledge of life in the sea, as reflected in the current textbooks or monographs on the subject. Marine life may be studied in two ways, (*a*) by working along the narrow strip (tidal belt, intertidal zone) exposed along the coasts of the continents at low water, and (*b*) by investigation of the off-shore waters, and of the sea floor, from vessels. The tidal belt is naturally much more accessible than the oceans, and has the advantage that one can walk over it and see it as a whole; moreover, in connection with the rise and fall of the tide which alternately covers and uncovers it, it presents a peculiarly changeable and fascinating environment for life. The ocean floor can never be examined in nearly the same detail, except in so far as small areas can be seen by diving, a method which has marked restrictions. It is therefore rather unexpected to find that, in a broad sense, knowledge of the oceans has outstripped that of the tidal belt.

By far the most comprehensive general account of the sea as an environment for organisms is *The Oceans*, by Sverdrup, Johnson, and Fleming, a book which appeared in 1942. It surveys our knowledge of the seas very fully, and deals also with the plants and animals which inhabit them. It tells us relatively little, however, about life between tidemarks. Similarly, the most comprehensive book which has yet been written about animal life in the sea (*Tiergeographie des Meeres*, by Sven Ekman, 1935) deals with the sea and its floor as a whole, but, while part of it is relevant to the tidal region, it does not refer specifically to this belt. There is no general work devoted to the biology of marine plants on a world scale, though there are sections on their distribution in books mainly devoted to algal morphology (e.g. *The Structure and Reproduction of the Algae*, by Fritsch, 1945). If we turn to the literature of the intertidal zone itself, we find that, while it is vast, the bulk of it covers detail rather than gives broad outlines. Thus, while we can point to numerous works which deal with the systematics of shore-living species, the biology of particular plants and animals, or the ecology of small areas (especially very small ones), we cannot find many examples of broad-scale ecology, although a notable exception exists in the numerous papers by Fischer-Piette on the coasts of the English Channel. There have also been many books on seashore life, yet none of them attempts to provide a world-wide picture such as is supplied for offshore waters by the books mentioned above. The nearest approach to such a thing is *Between Pacific Tides*, an account of the Pacific coast of North America by Ricketts and Calvin, first published in 1939.

It has been our own persistent aim to do what we can towards supplying a broader picture of intertidal ecology than has yet appeared, and we have been working towards this end over the past thirty years in Britain, Australia, South Africa, Mauritius, and North America. During the ten years which we spent in South Africa (1931–40) we organized a coastal survey in which we were assisted by a dozen younger workers. This provided the first general ecological review of a coastline of nearly 2000 miles, and was published as a series of over fifty papers, the references to which will be found in the final item, *The Constitution of the Intertidal Fauna and Flora of South Africa*, Part III, in the *Annals of the Natal Museum*, vol. XI, 1948. During this survey the coast between the mouth of the Orange River in the west, and the frontier of Portuguese East Africa in the east, was visited at about 100 points, and throughout the work the seaweeds and animals were considered in their relation to one another. From this project arose two others, one or both of which we hope to develop in the coming years. The first is to survey the British coast in the same way as we did the

South African, because in spite of all that has been published the material still does not exist for a broad ecological account of it. The second is to write a book on plant and animal life between tidemarks in the world as a whole. It was in connection with this second project that the journeys to North America described in this article were made. It is obvious that any book which deals with an area as vast as the whole world can do so only on the basis of a series of samples. We had seen, before 1947, a number of such samples, but we felt that there were certain others which we ought to see at first hand before embarking on our book. It so happened that they could mostly be found on the very varied coasts of North America.

On the first expedition we arrived at New York on 1st January, 1947, and left again on 25th January, 1948. During the intervening thirteen months we started work on the Atlantic coast in Florida, where we bought a car in which the rest of our journey could be made. The work required a rather massive amount of equipment, and by far the most economical method of transporting this and ourselves was to drive. From Florida we went first to Charleston in South Carolina, thence to Beaufort in North Carolina. After this we crossed the continent, with a pause at Washington, to Nanaimo in British Columbia, and thence moved south to California, ending at San Diego near the Mexican border. We covered altogether some 15,000 miles, and our schedule allowed us to stop for about two months at each of the main centres from which we wished to work. Though a period of two months is not long, a surprising amount can be seen on the shore during such a time by two people working together who have been doing similar work for many years previously. The expedition was made possible by grants from several institutions and by the kindness of various American marine stations in providing us with facilities. It is a pleasure to acknowledge our indebtedness to all who helped us; we have done so in more detail elsewhere.

The North American continent offers an immense variety of seashores, from the tropical coasts of Florida and the Panama region, through warm-temperate and cold-temperate variations to the more or less icebound northern regions. A great deal has been written about the biology of American shores, but there are relatively few general ecological accounts. We chose our localities as far as possible in regions which not only offered what we ourselves wished to see, but of which the general ecology had not been described. Our first objective was to see something of the Florida Keys, that strange chain of low islands strung out between Miami and Key West. We did not specially need to see a typical tropical shore, as we had seen a variety of these in Australia and the Indian Ocean, but Florida provides a very exceptional tropical area in which, in a very shallow, sediment-laden sea, a strangely limited intertidal population inhabits reefs of clinker-like coral rock (figure 2). It was the abnormality of this area which attracted us, as we hoped that by comparing it with more ordinary tropical regions some of the principles which control its peculiarities would be revealed. After leaving the Keys we went on to the northern part of Florida and North and South Carolina, where (between Cape Canaveral and Cape Hatteras) another unusual stretch of coast is to be found. In this case the marine climate is warm-temperate, but the inhabitants of intertidal rock (on which our attention is concentrated) are subjected to adverse conditions of a different type from those of southern Florida. The coastline is predominantly sandy, and there are few outcrops between tidemarks of any material harder than peat; their absence is partly made up for by the existence of rough, rocky breakwaters, some of them very large, which are very like natural reefs. In this area one can study not only the reaction of warm-temperate North Atlantic species to the presence of small rocky areas lost in seas of sand, but also (especially in North Carolina) the interesting overlap between northern cold-water species and southern warm-water ones. Another peculiarity of the northern part of this area is that those very characteristic shore animals, the limpets, which are of almost world-wide distribution, do not seem to be present at all on open rock-surfaces on the Carolina coasts which we visited.

On the Pacific coast our three centres offered entirely different sets of conditions. Here we were dealing everywhere with rich and abundant marine populations not subjected to adverse conditions, the marine climate being cold-temperate in the north and warm-temperate in the extreme south. At our first station, Nanaimo, in a region of quiet creeks showing reduced wave-action, there flourishes an astonishing marine population in water the salinity of which, while a good deal below that of normal sea-water, is not low enough to create estuarine conditions. It is a peculiarity of the fauna and flora here that many of the common species are very large and striking

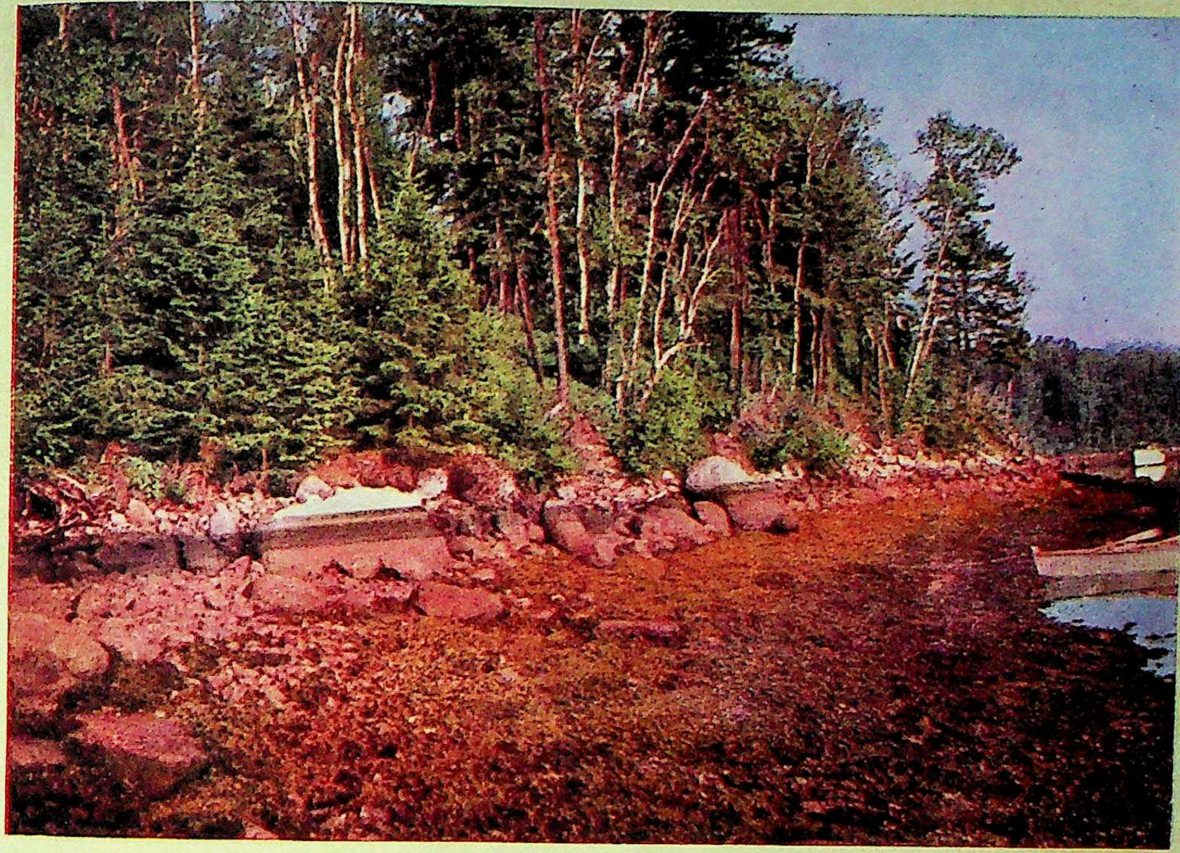

FIGURE 1 – *A view of the shore at the entry to Mason's Cove, one of the narrow marine inlets communicating with St. Margaret Bay, on the Atlantic coast of Nova Scotia. The inlet is remote from the open sea, and in hard winters may freeze over its whole surface for some time. This photograph, taken in summer, shows a variety of intertidal zonation which is characteristic of such inlets in Nova Scotia. Below the trees, which approach very near to high-water level, the granite boulders which line the shore show a whitish band. This represents the region in which the natural pale grey or whitish colour of the granite is most clearly visible; above this level it is commonly obscured by land-lichens and other vegetation, below it by intertidal agencies. Below this pale band is a black zone, very sharply marked and showing a striped appearance in places. This zone is due to a film of blue-green algae (often blackish in colour) and intertidal lichens, and is submerged by the sea only at the higher spring tides. Below this again lies a belt in which the granite is discoloured to a buff or pale-brown tint. There follows a wider zone carpeted by fairly large brown seaweeds (*Fucus *and* Ascophyllum*), and this seaweed zone shows a gradual change in colour from a yellowish brown above to a darker shade below, the colour change corresponding to a change in the nature of the population. The photograph was taken at low water of a moderate tide; but sometimes the tide falls lower than this and exposes a muddy zone below the belt of seaweed. The latter belt corresponds approximately to the midlittoral zone mentioned in the text.*

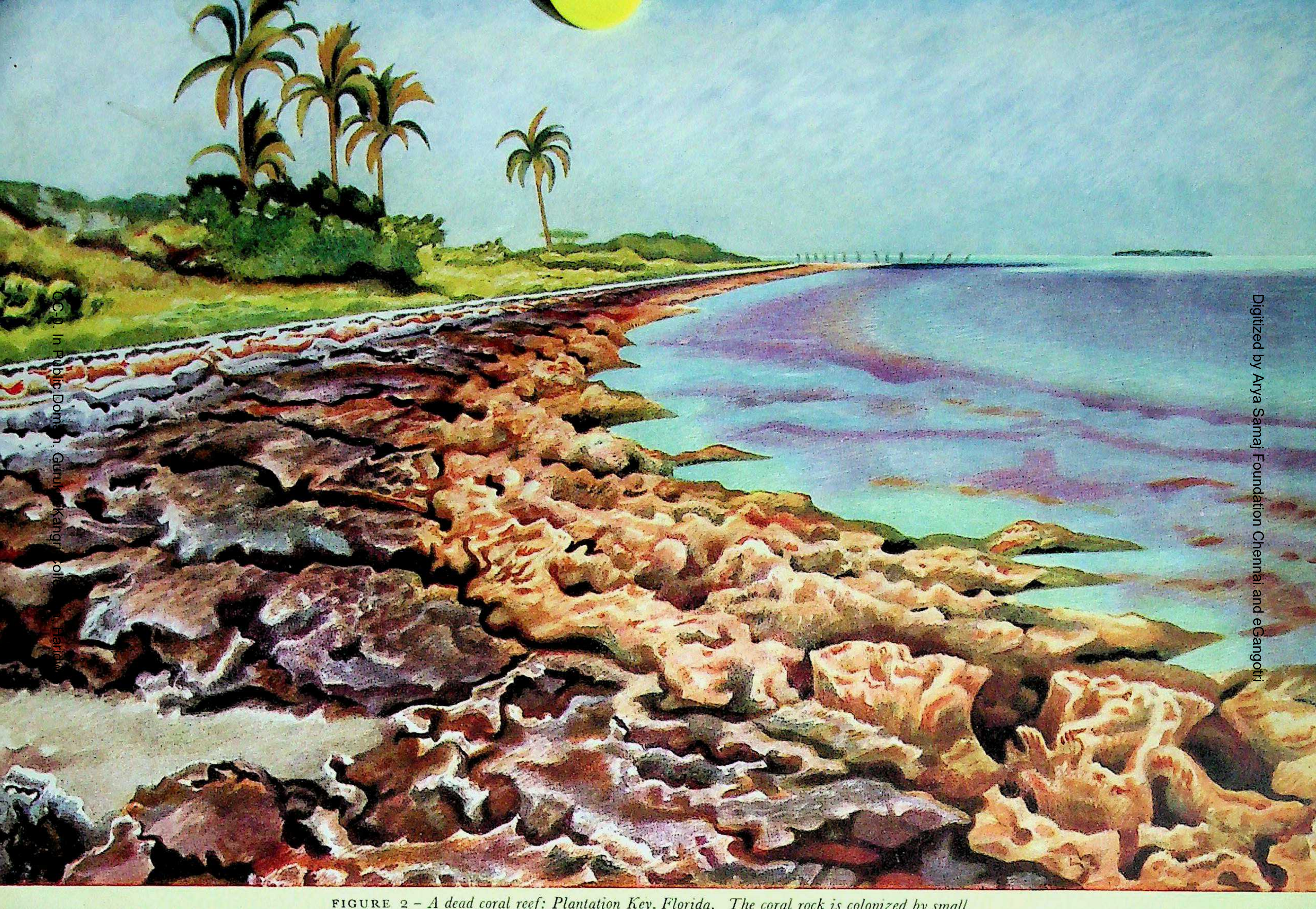

FIGURE 2 – *A dead coral reef: Plantation Key, Florida. The coral rock is colonized by small organisms which occupy zones in each of which the colour of the rock is affected in a different way.*

organisms which occupy zones in each of which the colour of the rock is affected in a different way.

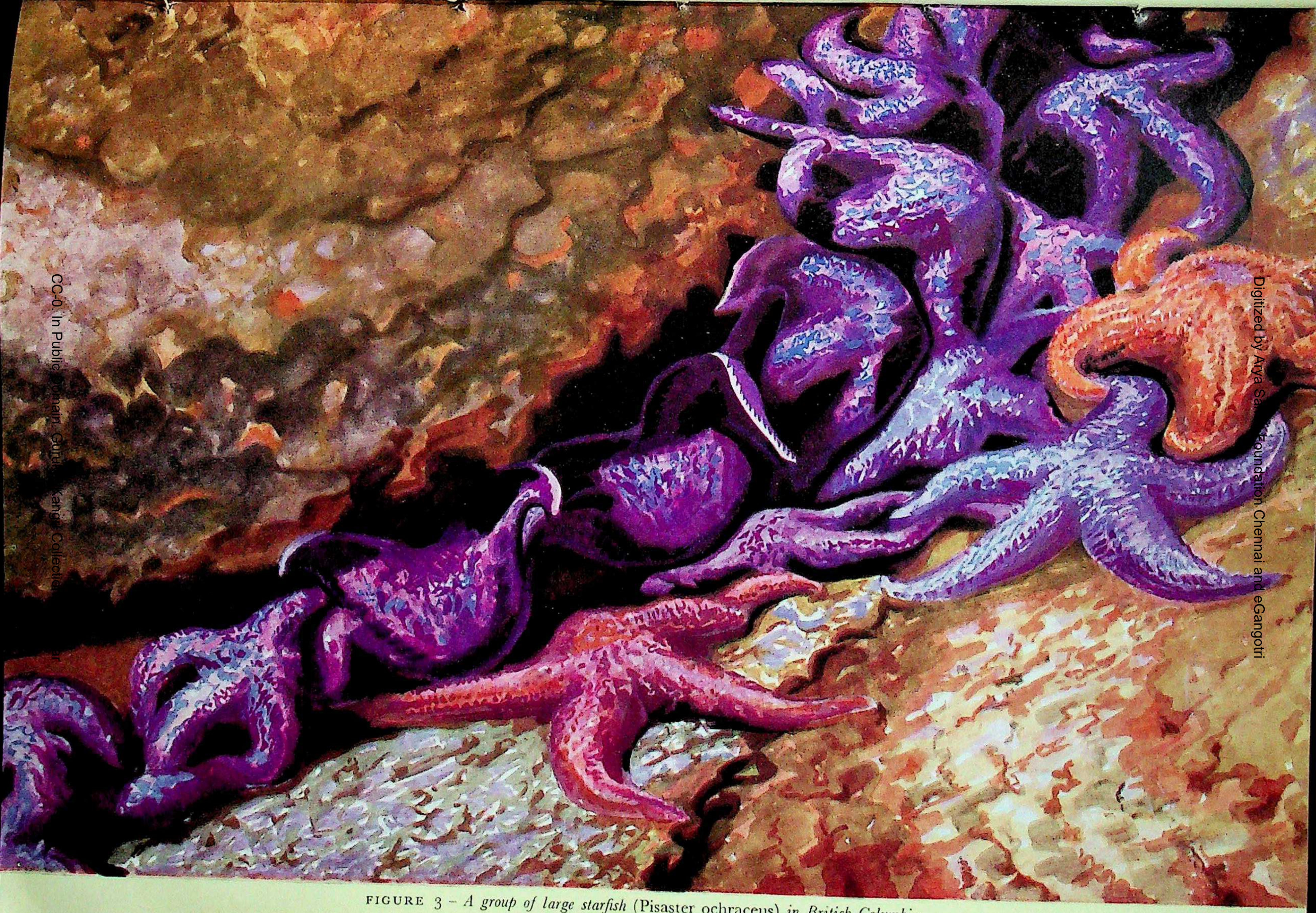

FIGURE 3 – *A group of large starfish* (Pisaster ochraceus) *in British Columbia.*

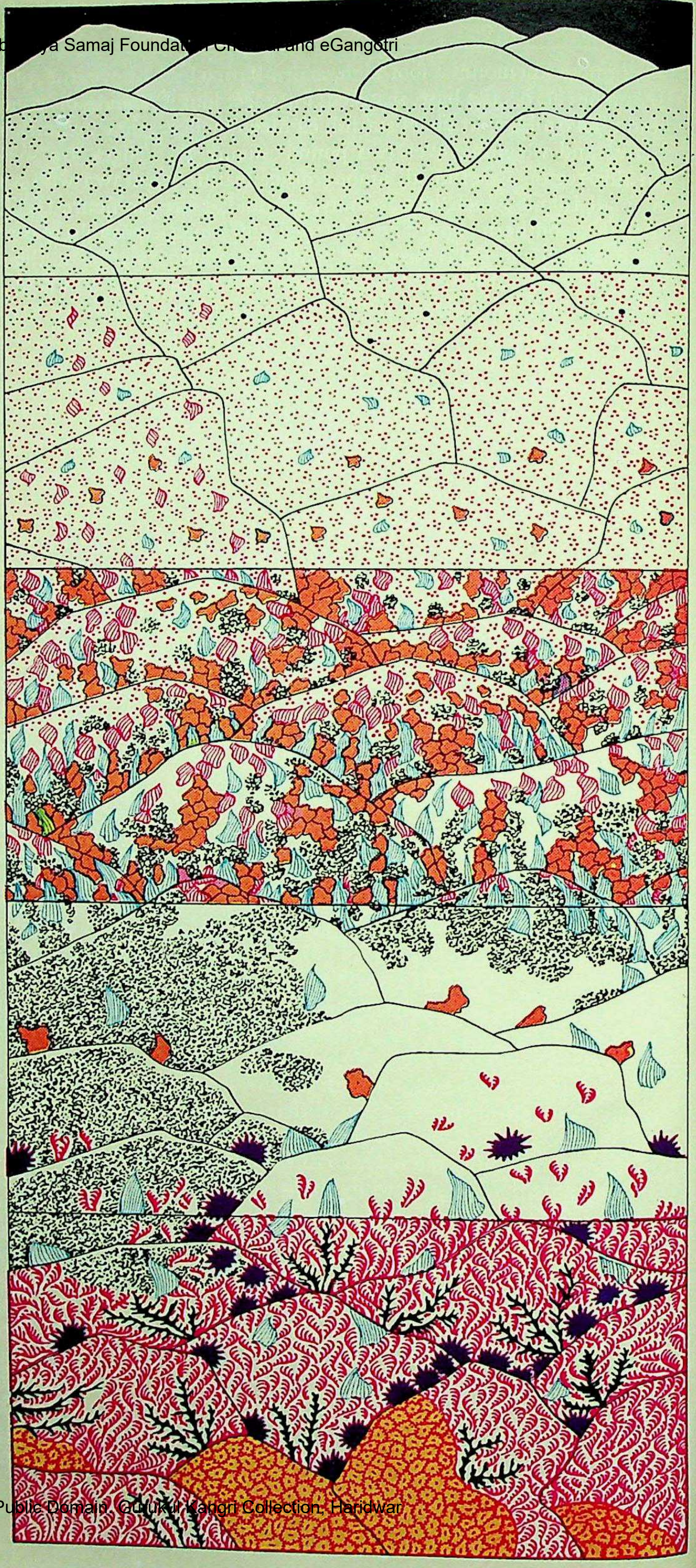
ANEMONES (*Aiptasia*)
BARNACLES (*Chthamalus*)
BLACK ZONE
SMALL SNAILS (*Littorina*)
MIXED ALGAE OF LOW LEVELS
MUSSELS
OYSTERS
PORPHYRA
SARGASSUM
ULVA AND ENTEROMORPHA
SEA URCHINS (*Arbacia*)

FIGURE 4 – *Diagrammatic representation of the arrangement in zones of some of the commonest plants and animals on rocky breakwaters near Beaufort, North Carolina. The lowest zone represents the infralittoral fringe, the highest the supralittoral fringe. Between these lies the midlittoral zone with three subdivisions.*

—plumose anemones a foot high, acorn-barnacles six inches across the base, seaweeds forty feet long, and above all bright violet starfish eighteen inches across and weighing over two pounds (figure 3). In this region we studied, among other features, a small island which has a sunny, gradual slope along its southern shore and a shaded cliff along its northern one; this provided a diagrammatic example of the differences which these two combinations of conditions produce in the distribution of the common intertidal species. At our next centre, the Monterey Peninsula and Point Lobos in California, there is a very strong contrast to Nanaimo, for here, while the population is again rich and varied and the sea of normal salinity, the coast is open to the Pacific swell, so that there are many wave-beaten promontories subject to seas of terrific power. So rugged is the coast, however, that despite the strong wave-action one can find, within a short distance of each other, areas showing all degrees of exposure to and shelter from the waves, so that the very sensitive reactions of the intertidal plants and animals to these variations can be studied. At our final station, La Jolla in southern California, is to be seen a rocky coast subject to wave-action stronger than that at Nanaimo, yet more moderate than that near Pacific Grove. Here, however, the population is warm-temperate, and the rock, while in the main abnormally soft, shows many local variations in hardness, with the result that one can study to advantage the very marked effects on the plants and animals of such variations.

During our second visit to America (June to September 1948) we studied rocky areas in Nova Scotia and Prince Edward Island, travelling altogether some 4000 miles. Here we were able to compare a typical open north-Atlantic coast, such as is found at Peggy's Cove near Halifax, with other coasts which, though occupying the same geographical region, show differences from the normal pattern owing to their special circumstances. Thus while the open coast near Peggy's Cove is little if at all affected by ice in the winter, some of the other coasts studied are scoured by it very markedly. Along the northern coast of Prince Edward Island, for instance, the ice may form for a mile out from the shore and pile up in irregular masses on the intertidal rocks, almost to the height of the cliffs. Factors other than ice are also involved.

One of the striking features of most rocky shores is the way in which the plants and animals populating them are arranged in horizontal bands, one above the other and often overlapping. These bands or zones vary in distinctness. Sometimes they are rather vaguely marked, sometimes their edges are so sharp that they might have been drawn with a ruler (as in the 'black zone' shown in figure 1). The existence of these zones and the possible reasons for it have been discussed extensively in the literature of the subject, but the problem is by no means fully solved. It is one to which we have paid particular attention. During the South African survey mentioned above we developed the idea that the zonation which is there apparent on the shore represents one of the possible variants of a fundamental plan which is of more or less universal occurrence. We tested this idea later in Britain, Mauritius, and East Africa, and more extensively during 1947–8 in North America. The information collected has yet to be developed before the theory can be applied in detail, but our general impression is that it has stood the test well. Stated in its simplest terms, the plan of zonation found on various coasts of the world tends to show (*a*) an arid zone transitional from land to sea, not covered by the sea at all high waters, the *Littorina zone* or *supralittoral fringe*; (*b*) a middle belt more regularly covered and uncovered by the sea, the *Balanoid* or *midlittoral zone*; and (*c*) a lower zone uncovered only at the lowest tides, the *infralittoral fringe*. This is, however, an extreme simplification, and each of the main zones (especially the midlittoral zone) shows subdivisions on many coasts, and there are complications of all descriptions. An example of zonation as developed on breakwaters near Beaufort in North Carolina is shown in figure 4, and in figure 1 is reproduced a photograph illustrating the zonation in a protected inlet in Nova Scotia.

While our American expeditions consisted primarily of field work and the collection of information, this was only the first step towards the object in view, which is to elucidate, by a study of the ways in which populations vary under all sorts of different conditions, the fundamental principles at work behind the surface appearances. These principles cannot, however, be formulated until a much more searching examination of the facts has been made than has yet been possible. There is also a large amount of information in the literature which will need to be tabulated and co-ordinated before the book towards which we are working can be written, but the task—almost impossible for anyone who has not seen a great variety of sea shores at first hand—will be much facilitated by this recent addition to our own field experience.

The International Union of Pure and Applied Chemistry

R. DELABY

'Chemistry,' according to Duclaux, 'is the basis of everything, and nothing escapes it.' Time has emphasized the truth of this sweeping generalization; today chemistry plays a dominant role in every civilized country. The need for international co-ordination in chemistry was first recognized by the formation of the International Association of Chemical Societies, founded before 1914. This has been succeeded by the present International Union of Pure and Applied Chemistry, of which Professor Delaby is Secretary-General.

Among the ten unions which at present form the International Council of Scientific Unions (I.C.S.U.), the International Union of Pure and Applied Chemistry, founded in 1919, has given ceaseless proof of its achievements. To try to give here even a summary account of its achievements would be impossible. This article recalls its origins, describes its present structure, and demonstrates its active participation in scientific progress.

Scientific societies contribute to progress by facilitating the exchange of information between scientists carrying out the same kind of research.[1] A second stage consists of bringing together groups in the same branch of science, founded in the same country, into a federal organism. Finally a union supplies, on an international plane, the indispensable ties between societies through the mediation of these national organisms.

This is the idea of the International Union of Pure and Applied Chemistry, which is: 'to organize permanent co-operation between the chemical associations of the membership-countries, to co-ordinate their scientific and technical resources, and to contribute to the advance of chemistry in the whole range of its domain, especially through the organization of conferences, congresses, and symposia.' This rubric, from Article 1 of its statutes, has not been appreciably changed over the last twenty years.

ORIGINS

The armistice at the end of the first world war had not yet been signed when the delegates of the scientific academies of the allied nations met in London in October 1918, and then in Paris the following month, with the intention of forming an International Council of Research. This body set itself in particular the task of co-ordinating the activities of the different branches of science and their practical application, of establishing contacts with the governments of the member-countries, and of facilitating the formation of international groups capable of contributing to the progress of science.

From the latter point of view, chemists of many countries had been concerned with their mutual relationships well before 1914: there was already in existence an International Association of Chemical Societies, including about fifteen societies, presided over by the famous French organic chemist Albin Haller and subsidized through the philanthropic generosity of Ernest Solvay. That was only a beginning. In November 1918 the Society of Chemical Industry received Paul Kestner, president and founder of the *Société de Chimie Industrielle*, and on this occasion negotiations were begun on exactly the same subject as that proposed by the International Council of Research. They ended in a conference in Paris in April 1919, bringing together the chief scientific and industrial groups of the allied countries: Belgium, U.S.A., France, Great Britain, and Italy. The main decision taken was that the chemical associations in each country should be invited either to create a national council made up of their delegates, or to form themselves into a federation; these national organizations were then to be grouped together into a confederation, which would afterwards become international by inviting the neutral countries to membership. In this way each country would send to the conference delegates representing the whole of its scientific and industrial associations, and no longer the delegates of a single society as in the former International Association of Chemical Societies, the dissolution of which was being considered at that time. A provisional council was nominated, and its president, Charles Moureu, *Membre de*

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[1] *Cf.* ENDEAVOUR, *The Role of Scientific Societies*, 1947, 6, 49.

l'Institut de France, was specially charged with the task of establishing contact with the International Council of Research, the project for which was under the aegis of the academies.

The Interallied Confederation of Chemistry was formed three months later in London; it adopted statutes, elected a board, established its provisional headquarters in Paris, and gave the Italian delegation the task of preparing for the next meeting in Rome in June 1920.

A delegation appeared immediately before the Chemistry Commission of the International Council of Research, which was holding its meetings in Brussels (22nd July, 1919); the delegation requested the integration of the new confederation, which was to have autonomous power 'within the framework of the organizations foreseen by the Scientific Academies, as the chemistry section of the International Council of Research.' In the course of this meeting, and following upon a favourable referendum of the members of its council, the International Association of Chemical Societies was declared dissolved. It was replaced by the Interallied Confederation, which was admitted into the International Council of Research, with the adaptation of its statutes to the general principles laid down by the Council; its title henceforth was to be the 'International Union of Pure and Applied Chemistry.'[1] In recognition of services previously rendered by the International Association of Chemical Societies, the presidentship was offered to Albin Haller, who, however, declined this unanimous offer from his colleagues, and Charles Moureu was elected the first president.

CONSTITUTION AND PROCEDURE

The Union's activities are carried out by a council through sections, such as inorganic chemistry, organic chemistry, biological chemistry, physical chemistry, analytical chemistry, applied chemistry, and through commissions, most of which are attached to these sections. Their meetings, attended by the whole or part of the Union and designed to take place at least every two years, are known as conferences.

The Council is composed of delegates, nominated by the subscribing organizations; the number of delegates depends on the category to which the corresponding country belongs, the three categories themselves being fixed according to the activities in the realm of chemical science which that country develops. The Council is very similar to the Houses of Representatives existing in democratic countries where they possess legislative powers. It deals with scientific as well as administrative and financial questions. At the present time 31 countries possess an organization attached to the Union.

Executive powers were vested in a board elected from the Council and composed of, at the most, 17 individuals: a president, six vice-presidents, six elected members, a general secretary, a treasurer, and the two past-presidents.

Experience having proved the difficulty of bringing together all the members of the board between conferences, the powers of the board have been delegated to an executive committee formed by the president, a vice-president, one elected member, the general secretary, and the treasurer.

The work is shared between permanent and temporary commissions, charged either with the administration of the various organizations of the Union, such as the permanent commission for finance, or with the study of given problems. The scientific and technical commissions are composed of specialists. They may include qualified members elected by the commissions, and delegate members of interested bodies such as offices of weights and measures and research institutes. They can add to their numbers, in an advisory capacity, national representatives and observers, invited by their presidents.

Provision is also made for affiliated committees which, for example, set out to unify methods of analysis or of control in a specialized discipline; the extremely active commission for the study of fats is of this kind, and it would be desirable to include in the Union other similar commissions.

Since the war, the I.C.S.U. has created mixed commissions from among the international unions, attached to a central union which is the one most clearly interested. Thus the Union of Chemistry is the central union of the commission on standards, units, and constants of radioactivity, which includes the delegates of the International Union of Pure and Applied Physics.

These commissions are to the Union what the circulation is to a man; they supply the organism continuously with new blood. At the fourteenth conference President Bogert appropriately recalled the fact that the president of a commission should be abreast of research carried out in his branch by other individuals and institutions recognized generally as outstanding; for thus he can make an infallible selection from among his colleagues. 'He is like a generalissimo in a high observation post, with the field for his operations spread out before him. His office should be the world's authoritative information centre for the subject covered.'

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[1] From 1930 to 1949 it was called simply '*Union Internationale de Chimie*'; at the 15th Conference (Amsterdam, 5–10th September, 1949) it was thought preferable to state in the title that the Union interested itself in both the theoretical aspect and the applications of chemistry.

CONFERENCES AND SYMPOSIA

Since its formation the Union has held fifteen conferences. At first these meetings were annual, so as fully to ensure an intellectual intercourse between chemists throughout the world and to take many desirable decisions; then the rhythm became two-yearly after 1928, apart from a four-year interruption between 1930 and 1934 and a much longer break (1938–47) due to the second world war; but in 1946 contact was reopened in London.

In principle, each conference first hears a presidential report on the general state of the Union and a report from the treasurer on the financial situation. Administrative questions are next discussed. After these, it is the scientific subjects treated by various commissions which particularly hold the interest of the conference; the presidents report upon the work which has been carried out—work not seldom leading to international conventions, or standardizations, or progress of other kinds. It would be banal to recall the universality of the world of chemistry, and Duclaux was prophetic when, more than half a century ago, he said: 'Chemistry is the basis of everything, and nothing escapes it.'

Proceedings were published after each conference, and now form an impressive collection of 2142 quarto pages. It should be added that there are certain reports which are too highly specialized or too voluminous to be included in proceedings; some of them have been circulated by publishing houses, e.g. 'Tables of Reagents for Mineral Analysis,' available in three languages (409 pp.), and 'Recommended Reagents' (288 pp.), which constitute two fundamental reports of the commission of new analytical reactions and reagents.

In addition to the conferences and to the congresses (the history of which will briefly be sketched), the Union has recently made arrangements for a number of more restricted reunions called symposia; qualified specialists will here speak on subjects which are still in process of development, or will treat more particular topics. Two symposia on macromolecular chemistry (Liège, 1948; Amsterdam, 1949) presided over by Professor H. Mark, have already proved a great success.

CONGRESSES OF PURE AND APPLIED CHEMISTRY

Before the formation of the Union, international congresses of applied chemistry were held periodically and assumed a steadily increasing importance. The initiative in this was taken by the Belgian Association of Sugar Refining Chemists, soon seconded by the analogous association in France and her colonies. The first congress was held at Brussels in 1894, and the second in Paris in 1896, when 1500 members presented 194 reports, a remarkable achievement for the time. Others followed: Vienna (1898), Paris again (1900), Berlin (1903), Rome (1906), and London (1909); the eighth and last congress to be held before the first world war took place at Washington and New York in 1912, where 4400 chemists, divided into 23 sections, took part and 789 memoranda were discussed. Thus it is for more than fifty years that chemists have been trying to encourage international meetings.

However, the associations which had until then assured the success of these congresses decided that their organization should devolve upon the Union, and the first statutes, in some twenty articles, establish their constitution. The present ruling, which is deliberately less complicated, states that International Congresses of Pure and Applied Chemistry should in principle be held once every four years, and their organization is entrusted to a committee established by the country in which they are to take place; this committee draws up the programme in collaboration with a commission delegated by the Council of the Union.

CONCLUSION

In concluding this summary, mention should be made of the extremely sympathetic atmosphere in which the discussions, the meetings, and the communications of the Union have taken place. We should also emphasize the slenderness of the resources which so far have been available for creating this 'World Parliament of Chemistry.' It has been above all the work of disinterested men, inspired by an ideal. UNESCO is at this moment considering the scope which in the future should be given to international scientific unions. May it furnish them with powerful means, for they are not a negligible factor in the effort to secure that universal peace desired by all men of good will.

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Plant cancer

R. J. GAUTHERET

For some time biologists have suspected that an analogy existed between plant tumours and animal cancers, but only recently has it been possible, by use of the method of tissue culture, to establish this analogy. This technique has revealed for the first time that certain bacteria, or substances belonging to the family of heteroauxins, provoke in plants tumourous phenomena similar to those characteristic of cancer. This article is a review of the most recent work in this field, and of the ideas which it suggests for future progress.

NEOPLASMS

Imagine in an organism a cell which, after having functioned for months or years in harmony with the myriads of other cells, suddenly becomes capable of multiplying in a disorderly manner. This cell will give rise to a mass of tissue with abnormal structure: that is, to a tumour. Sometimes the proliferation will be slow and limited; the tumour then produces no important functional disturbances, and remains of a mild character. The warts and wens common in man, and the galls produced on the leaves of many plants by certain insect larvae (figure 1), belong to this type of tumourous growth. If, however, the cellular multiplication becomes completely disorganized, the tumefacient elements may invade the organs of the individual like parasites, and provoke grave and often fatal disorders. These malignant neoplastic developments are known as cancers.

ANIMAL CANCER

Animal cancers have for a long time attracted the attention of biologists, but their nature is still very obscure. Cancer is thought to be a disease of the cell itself. It is not transmitted from cell to cell, but spreads from one organ to another by metastases, that is, by cells which detach themselves from the original tumour and are carried by the blood-stream or the lymph to distant points, where they start new cancerous centres.

This method of propagation shows that the cancerous cell is an element endowed with special properties. The study of tissue culture has thrown some light on the nature of this specificity, showing that the cancerous elements have fewer nutritive needs than the corresponding normal cells. It looks as if the cancerization consists in an increase in the synthesizing power of the cells, which results in unlimited multiplication at the expense of the nutritive substances in the organism. Further investigations on the cause of cancer have shown that it is not of bacterial origin, and have revealed the frequent intervention of carcinogenic viruses and the occurrence of tumourous phenomena produced by physico-chemical processes, e.g. by the action of certain hydrocarbons and other substances, and of certain radiations. It is also obvious that genetic factors play an essential part in the development of cancer, because within a given animal species certain lines of descent are susceptible to cancer, while others, though related, are completely immune.

The fact that tumefaction often requires the simultaneous action of several factors has prevented the welding of the ideas suggested by these discoveries into a single theory. Thus, certain cutaneous cancers of the rabbit require the combined action of a virus and one of the carcinogenic hydrocarbons. The case of the mammary tumour of the mouse is still more complex, because this neoplasm occurs only by the co-ordinated action of definite genetic characteristics, a virus transmitted by the milk (lacteal factor), and a sufficient quantity of oestrogenic hormone.

CROWN-GALL

About forty years ago, two American phytopathologists, Smith and Townsend, suggested that the study of plant tumours would furnish data that might throw some light on the problem of animal cancer. Their attention was attracted by crown-gall, a luxuriant tumour which sometimes develops on certain plants. From this tumour they isolated a rod-bacterium, *Phytomonas tumefaciens*, which when inoculated into healthy plants produces new tumours (figure 2). It therefore seemed out of the question that crown-gall could be in any way similar to animal cancers, since these were certainly not of bacterial origin. Smith nevertheless tried to establish some relation, based on the fact that plants afflicted with crown-gall produce metastases analogous to those produced by animal cancers. Curiously enough, these metastases do not involve bacterial cells, and it thus seems possible that they result from some action at a distance exercised by the *Phytomonas* contained in the original tumour (figure 3).

Experiments performed about ten years ago seemed to confirm this view, showing that *Phytomonas tumefaciens* synthesizes indoleacetic acid (Berthelot and Amoureux), a substance capable of stimulating the multiplication of plant cells (figure 4). This substance might accumulate in the tissues to a concentration of the order of 10^{-7}, which is sufficient to produce an active proliferation of the cells. It would later diffuse into the tissues around the original centre, which explains the formation of secondary tumours without the direct agency of bacteria.

In view of these results it was not possible to attribute a particular specificity to the cells of crown-gall, and the idea of plant cancer was therefore dropped.

THE CANCEROUS NATURE OF CROWN-GALL

However, two American biologists, Braun and White, reluctant to accept this simple explanation of the tumourous phenomena produced by the *Phytomonas*, went further into the question and compared the physiological properties of crown-gall cells with those of normal elements from similar plants, using the method of tissue culture.[1] They isolated fragments of secondary tumours which, as stated above, do not contain bacteria, and tried to cultivate them in a medium containing mineral salts, a sugar, and traces of glycine and vitamin B_1. The attempt was successful, for by this method they obtained a strain capable of multiplying indefinitely (figure 5). In spite of the absence of *Phytomonas*, these tissues retained their tumourous characteristics in the culture, and when grafted on to a healthy plant they produced new tumours (figure 6). It thus became obvious that the action of the bacteria of crown-gall is simply that of starting the tumourous processes, and these persist without the aid of bacteria. The crown-gall may therefore be considered as a true cancer.

COMPARISON OF CROWN-GALL CELLS AND NORMAL CELLS

In spite of this work, the problem of plant cancer remained unsolved. Braun and White did not compare the physiological properties of cancerous cells with those of normal cells, for they were unable to cultivate normal tissues. In order to solve the problem we undertook the cultivation of crown-gall tissues of several species, such as viper's grass (*Scorzonera*) and Jerusalem artichoke, of which we already knew how to cultivate the normal tissues. In attempting to determine the exact nutritive requirements of these two types of culture, it was found that the media used for cultivating tumourous tissues which contain no growth-promoting substances become capable of sustaining the proliferation of normal tissues by addition of indoleacetic acid. In order to elucidate the significance of this difference in behaviour between normal and tumourous tissues, our student Mlle Kulescha analysed the growth substances or auxins synthesized by the two types of tissue. She found that while normal colonies produce only an insignificant quantity of auxin, which, expressed in indoleacetic acid content, corresponds to a concentration of $0{\cdot}1$–$0{\cdot}3 \times 10^{-8}$, the concentration in cultures of bacteria-free crown-gall tissues is of the order of 5×10^{-8}, sufficient to activate the cell multiplication. As a result of these experiments it is clear that the tumefaction consists in the intensification of the power of the cells to synthesize the auxins which are essential factors in their multiplication. They thus become capable of multiplying indefinitely in the parenchymatous tissues of the normal plant, even when these are poor in auxins.

MECHANISM OF TUMEFACTION

These investigations did not, of course exhaust the problem of crown-gall, as they did not provide any indication of the mechanism of the tumourous transformation. In order to understand this, it is necessary in the first place to explain how the modifications produced by *Phytomonas* can persist after the elimination of the bacteria. It might be assumed that the bacteria produce a permanent transformation of the cells, with the effect of intensifying the synthesis of auxins, but it then becomes necessary to explain how the bacteria can act in this manner.

CHEMICAL THEORY

Various experiments suggest that in the first place this transformation might be due to the indoleacetic acid manufactured by the *Phytomonas*. We have in fact shown by experiment that by submitting normal tissue cultures to suitable doses of indoleacetic acid over a period of several years they can sometimes be made to acquire the properties of tumourous colonies. This tumourous

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[1] ENDEAVOUR, 7, 75, 1948.

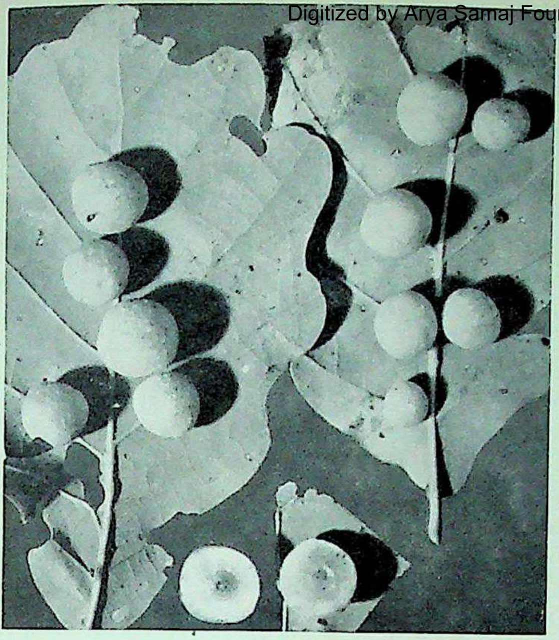


FIGURE 1 – *Galls produced on an oak leaf by a hymenopter larva. This neoplasm develops only slightly, and thus has a mild character.*

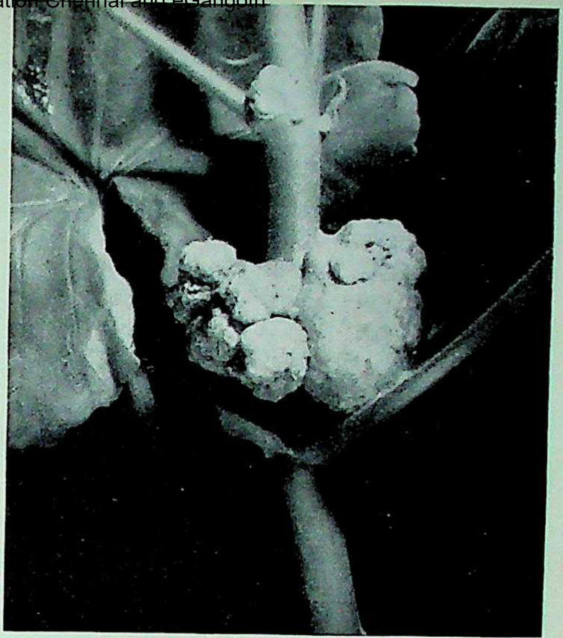


FIGURE 2 – *Crown-gall developed on a stem of pelargonium. This exuberant tumour is produced by inoculation with* Phytomonas tumefaciens *bacteria.*

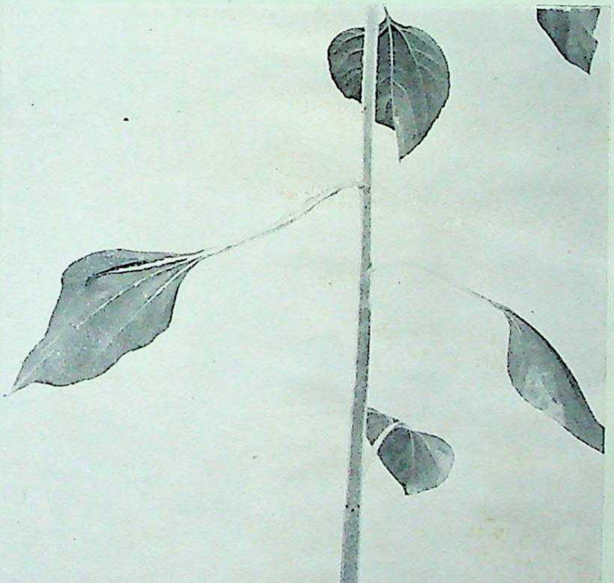
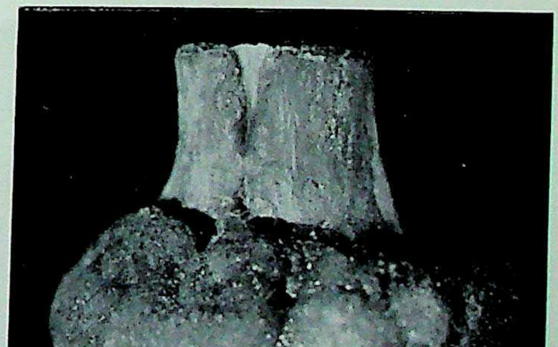


FIGURE 3 (*left*) – *Production of metastases by crown-gall. This photograph shows the stalk of a sunflower, which has been inoculated with* Phytomonas tumefaciens. *A tumour developed in the infected area (below); and later, secondary tumours appeared on a leaf some distance from the original source (top left). These secondary tumours were without bacteria (Braun and White).*

FIGURE 4 (*below*) – *Fragment of a root of* Hyoscyamus, *which has been cultivated in a medium containing indoleacetic acid in a concentration of* $1 : 10^6$. *It has produced a large parenchymatous protuberance under the action of the growth-promoting substance. The aspect and structure of this protuberance are analogous to those of neoplasms produced by crown-gall bacteria. However, as is shown later, the physiological characteristics of these neoplasms produced by indoleacetic acid are different from those of bacterial tumours.*



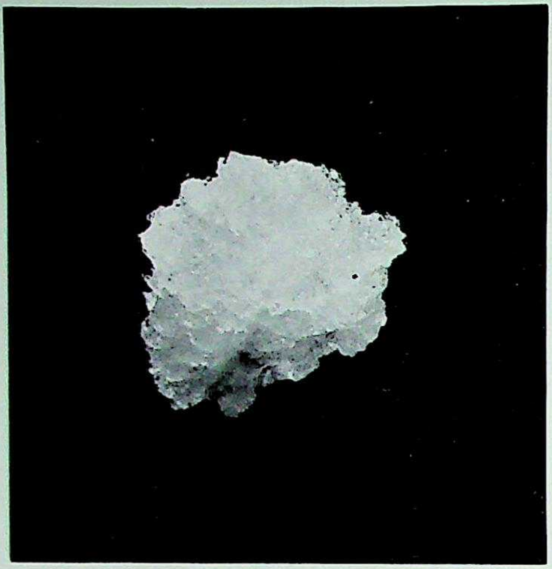


FIGURE 5 – *Culture of crown-gall tissues of the sunflower. This depicts an aseptic culture emanating from a secondary tumour free of* Phytomonas. *The colony shown in this illustration was derived from a strain which had undergone several explantations.* (*Braun and White.*)

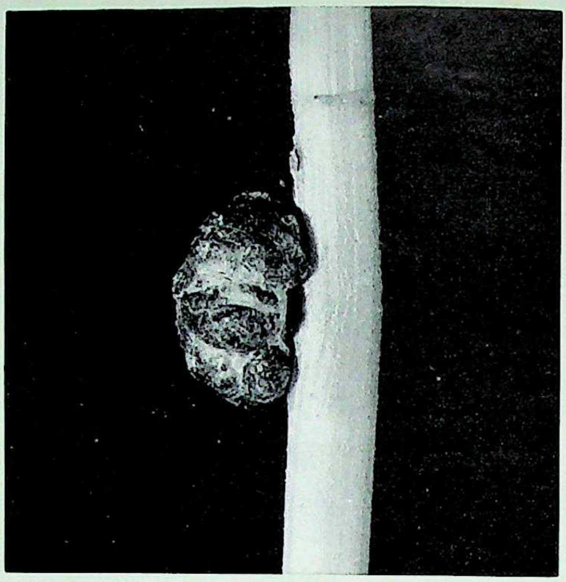


FIGURE 6 – *A tumour obtained by grafting an aseptic culture of crown-gall on to a sunflower stalk.* (*Braun and White.*)

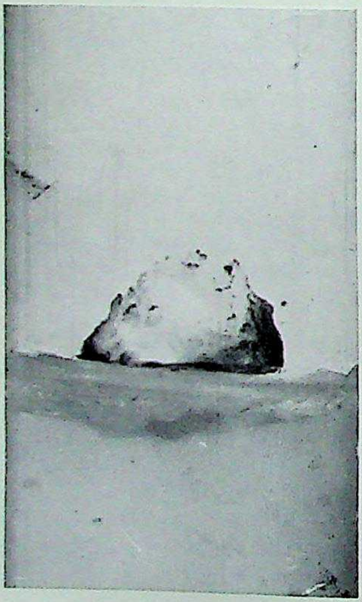


FIGURE 7 – *Culture of a normal tissue of viper's grass* (Scorzonera) *from a strain subjected to several explantations. These tissues manufacture only an insignificant quantity of auxins, and are therefore unable to multiply without indoleacetic acid. If grafted on to root fragments they do not develop. The colony depicted in the illustration is opaque and compact.*

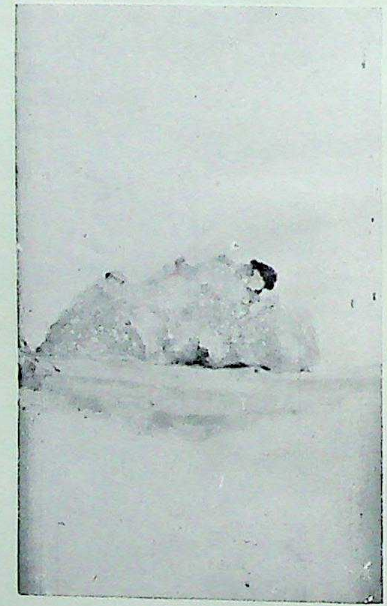


FIGURE 8 – *Culture of crown-gall tissues of viper's grass. This colony synthesizes a sufficient quantity of auxin to allow it to multiply in a medium without growth-promoting substances. When grafted on to a fragment of a normal root it can develop and produce a tumour. This colony has a translucent appearance.*

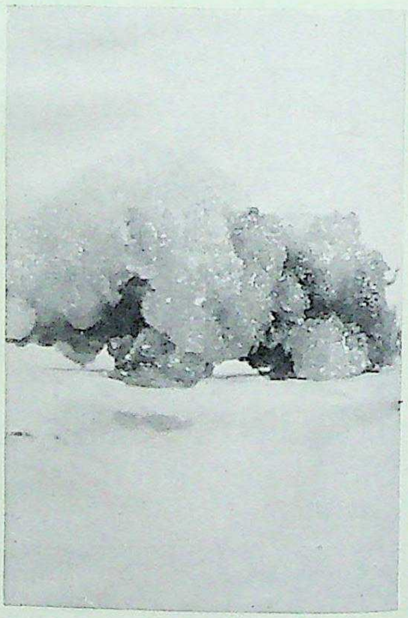


FIGURE 9 – *Tumourous colony from a normal stem of viper's grass tissues which has been treated for a prolonged period with indoleacetic acid. This stem has acquired the ability to produce a large quantity of auxins, and for this reason it is capable of multiplying without their addition. When grafted on to fragments of normal roots it is able to produce tumours. It is translucid like the crown-gall tissues, instead of opaque like a normal colony.*

transformation, produced by chemical processes, sometimes occasions sectorial mutations looking like those observed in yeast colonies. It manifests itself in the production, on the surface of a normal colony, of a translucent nipple, which can be transferred separately, thus supplying colonies of a new type with tumourous characteristics (figures 7, 8, and 9). These colonies manufacture auxin of a concentration comparable with that of crown-gall tissues (this corresponds to 3×10^{-8} of indoleacetic acid), giving them the power of multiplying vigorously in a medium lacking heteroauxins. In addition, they produce tumours when grafted on fragments of normal plants. Tissues transformed in this way are therefore similar to crown-gall tissues, and it seems plausible that, as stated above, the indoleacetic acid secreted by the *Phytomonas* is the direct cause of the tumefaction produced by this bacterium.

CRITICISM OF THE CHEMICAL THEORY

This theory, however, is not fully satisfactory. Several facts indicate that there is not likely to be any similarity between chemical and bacterial cancerization. The latter acts almost instantaneously and in a constant manner; to obtain it the *Phytomonas* need be present in the tissues for only ten hours, whereas the carcinogenic action of indoleacetic acid is very slow. A tissue may be treated with indoleacetic acid for many months or even several years and still keep its normal characteristics; then it may suddenly manifest tumefaction—this rarely happens, but when it does the action is very quick.

Bacterial cancerization is therefore an inevitable phenomenon, in which the *Phytomonas* plays a definitely specific part, while chemical cancerization is sporadic: it seems that the indoleacetic acid merely reveals potentialities of tumourous transformations inherent in the tissues. Moreover, this non-specificity of the carcinogenic action of heteroauxins is emphasized by the fact that other heteroauxins can act in the same way.

There are other phenomena that lead to differentiation between bacterial and chemical cancer. Certain plants, for example, do not develop tumours except under the combined action of *Phytomonas* and an external application of indoleacetic acid. This excludes the theory that indoleacetic acid might be the sole factor of the tumourous transformation. Further, the chemical theory provides no satisfactory explanation of certain properties of tumourous tissues, such as the phenomena of tumourous induction discovered by de Ropp and by Camus. When a fragment of a tumourous colony, of bacterial or chemical origin, is grafted on a healthy stump of an organ, it induces the formation of swellings possessing tumourous characteristics. As this action is very rapid it cannot be due to the indoleacetic acid manufactured by the tissues, since this substance is slow-acting. It must therefore be caused by some other factor.

THE VIROLOGICAL THEORY

As the chemical theory of plant cancer leads to serious difficulties, an explanation of tumourous phenomena may be sought in virus action. In the case of crown-gall, for example, the *Phytomonas* might be associated with a carcinogenic virus which survived after the elimination of the bacteria from the tissues. In the case of chemical tumours the carcinogenic virus would be of endogenous origin. This virological hypothesis of plant cancer is evidently only tentative. It is not altogether arbitrary, however, because some viruses are capable of breeding tumours in plants (Black). Furthermore, for the time being it represents the only plausible explanation of the production of cancerous phenomena by grafting.

THE NATURE OF TUMOUROUS TRANSFORMATION

The question of the nature of tumourous transformation remains. This does not arise if the virus theory is accepted, since the sole action of the carcinogenic virus becomes the manufacture of dividing substances, or increasing the synthesizing power of auxins of the contaminated cells. If the virological hypothesis is rejected, another theory must be framed.

For example, there is the possibility of a mutation produced either by bacteria or by indoleacetic acid. This conception is not free from objections; the inevitability characterizing bacterial cancerization does not in fact agree with the possibility of mutation, because this phenomenon is always sporadic. On the other hand, mutation appears more plausible in the case of chemical cancerization, which is a rare and rather irregular phenomenon. Recent observations, however, have shown that there are very numerous grades of intensity of tumourous transformation produced by indoleacetic acid, and this is not compatible with the idea of mutation. It thus appears that the cancerization of plant cells is not a genetic phenomenon, but that it is similar to the enzymatic adaptation so frequent in micro-organisms.

Heredity of pigmented tumours in fish

MYRON GORDON

> 'The pigmentary system, like all other systems, is subject to aberrations from its normal form, structure, and activity. In particular, neoplastic growths are found in many species of animals . . . in which pigment cells play the dominant role. Among these neoplasms are some of the most malignant tumours known, so that any light that can be thrown upon their origin and behaviour . . . is welcome.'—[Ross G. Harrison, *Biology of Melanomas.*]

Pathologists find that many kinds of tumours are of common occurrence in sharks, fishes, amphibians, reptiles, birds, and mammals [1, 10, 18, 28]. These tumours of vertebrate animals are similar in general structure and essential microscopic details to the corresponding tumours in man [21, 23, 24, 31, 32]. Appreciation of the similarities will be helpful in the interpretation of the fundamental biological nature of all neoplastic growths.

Among the newer living tools available to the cancer research worker are fish, which are particularly valuable for studies of normal and atypical pigment cell growth [18]. Pathologists who have studied and compared the black pigment cell tumours in the representatives of the six classes of vertebrates discovered that the melanoblast is the common cell type in the melanomas of all animals, including those of man [6, 19, 22, 24]. The melanoblasts taken from melanomas of living fish, mouse, and man appear to be almost identical when observed in tissue cultures, and thus seen in all their dimensions and in the fine details of cellular structure [20].

The early embryonic source of pigment cells has recently been discovered. In salamanders, birds, and mice conclusive experiments show that they arise from the neural crest [7, 26]. These early pigment cells are characterized by great mobility, and capacity to spread all over the body [7, 26]. In cyclostomes, elasmobranchs, fish, amphibia, and reptiles, the melanophores normally appear in the perineural, pericoelomic, and perivascular areas, as well as in the skin [34]. In birds and in mammals, pigment cells are generally confined to the epidermis, are less common in the dermis, are occasional in the meninges, and are rare in the deeper regions [34]. In man, a melanoma of the pigmented meningeal membrane of the brain has been described [9].

Pigment cells and their chromatic effects have long been one of the favourite subjects for investigators of problems in genetics. This is particularly true in the study of inheritance in fish, for some of these polymorphic species have a great variety of colour patterns [16].

The chromatophores which produce the various colour patterns in the lower vertebrates are generally known by the principal kind of pigment they contain. Thus, colour-bearing cells containing black pigments are called melanophores. Those which bear red granules are erythrophores; those which contain yellow colouring matter are known as xanthophores; and chromatophores containing guanin crystals are termed guanophores [2, 25]. Several kinds of chromatophore may form a single multicellular chromatic unit. Some chromatophores, especially among the fishes, are extremely complex, and a single cell may contain a combination of several colour elements; for example, the xantho-erythrophore has yellow and red pigments. The chemistry of this remarkable chromatophore has recently been determined, and it was found that in the xantho-erythrophores the yellow substance is made up of lutein and zeaxanthin, while the red pigment is erythropterin [12].

Neoplasms developing from melanophores are the commonest type of pigment cell tumour. Melanotic tumours have been found in the wild representatives of eleven orders of elasmobranch and true fishes [18]. However, in swordtails and platyfish no melanomas have as yet been found in over 20,000 carefully examined wild-caught specimens. Yet by genetic methods of breeding, hundreds of melanomas have been induced in the black-spotted hybrid offspring of the laboratory-bred Mexican swordtails and platyfish [3, 4, 5, 17, 18, 22].

Tumours arising from the more colourful of the pigment cells are relatively rare in fishes. In a twelve-year survey of 100,000 fish of the Sea of Japan, only one silvery tumour, a guanophoroma in a greenling, and one greenish tumour, an

PLATE I

ERYTHROMELANOMAS OF THE HEAD

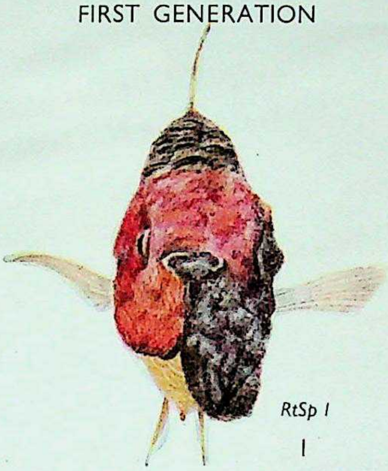
PLATYFISH X SWORDTAIL

Platypoecilus maculatus *Xiphophorus hellerii*

SECOND GENERATION

TWO YEAR OLD ADULTS

FIRST GENERATION



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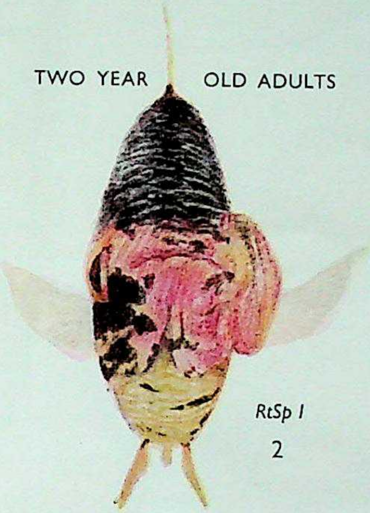
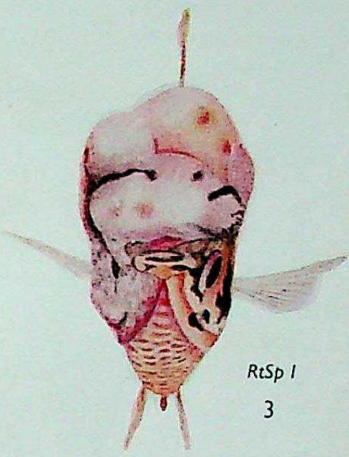


2

FIRST GENERATION



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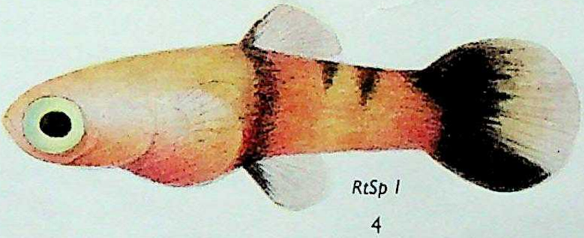
BACKCROSS GENERATION

ONE DAY OLD



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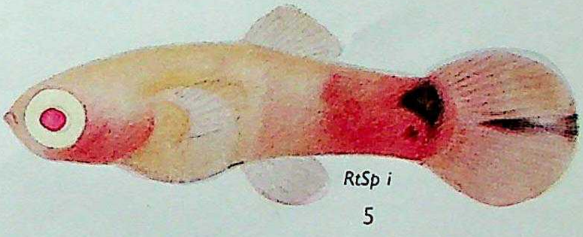

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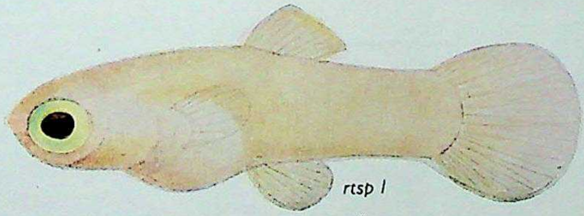

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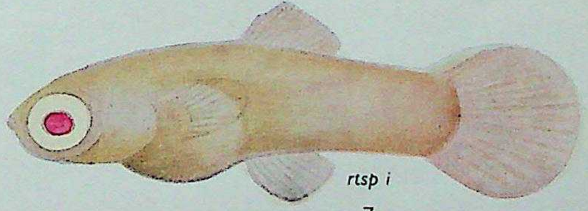


7

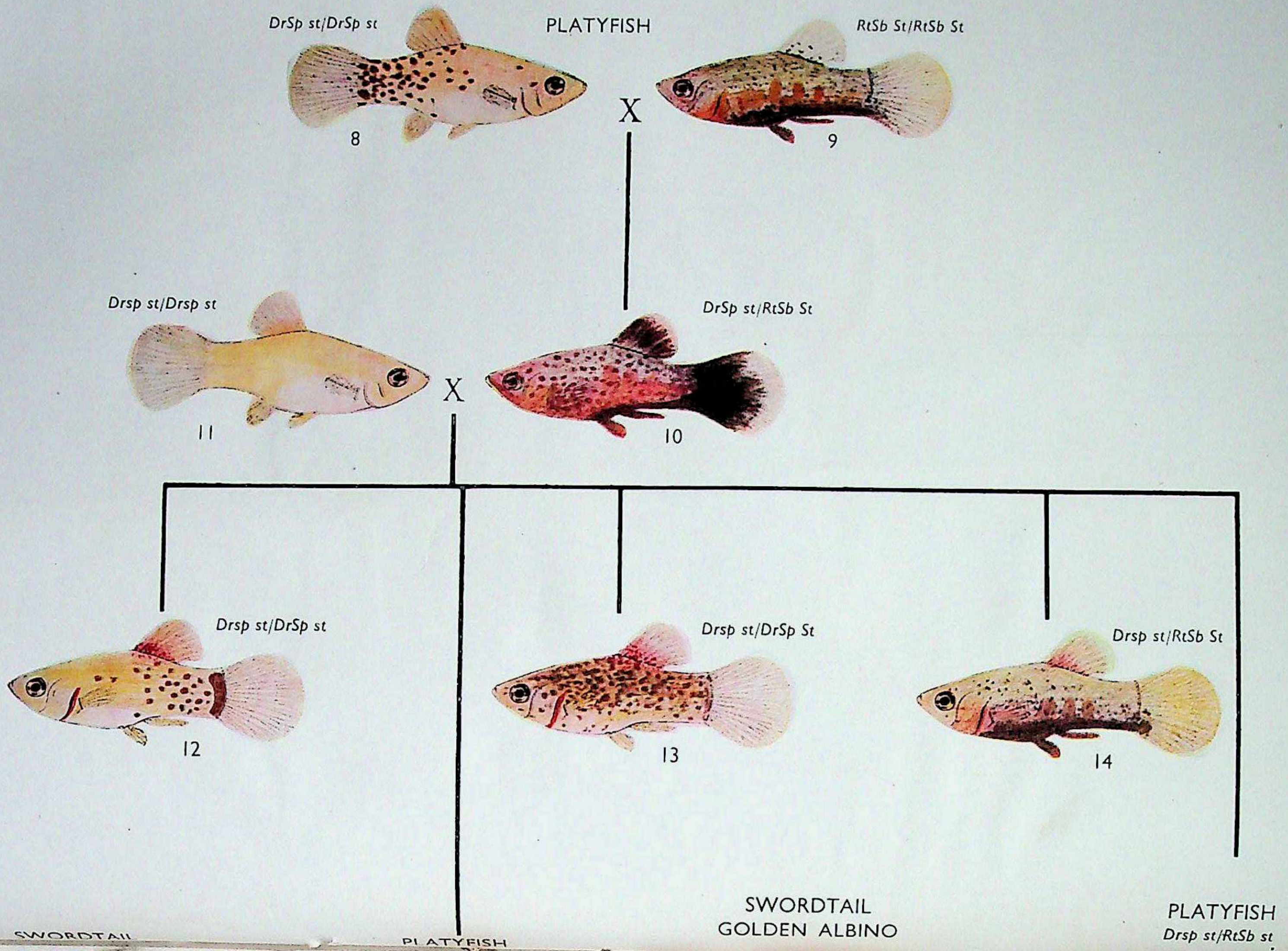
FIGURE 1 – *Head-on view of platyfish-swordtail hybrid number* 206–12 *with erythromelanoma of the head. This individual may be seen in lateral view in figure* 20. FIGURE 2 – *Platyfish-swordtail hybrid, offspring of number* 206–12 *and a normal hybrid. For another second generation hybrid with an erythromelanoma of the head see figure* 23. FIGURE 3 – *Platyfish-swordtail hybrid number* 206–14, *a variation in the form of the erythromelanoma of the head.*

The four phenotypes obtained by mating hybrid number 206–12 *back to a golden, albino swordtail.* FIGURE 4 – *Ruby-throated, spot-sided hybrid with typical coloration.* FIGURE 5 – *Ruby-throated, spot-sided hybrid with* ii *albino genes. Note pink eyes.* FIGURE 6 – *Golden, black-eyed hybrid.* FIGURE 7 – *Golden, albino hybrid. Note pink eyes.*

The outstanding type is the RtSp i (*figure* 5). *Ordinarily the albino gene* ii *inhibits the* Sp *gene's ability to form melanin pigmentation, but in the melanomatous individuals, like the one illustrated here, where* Sp *is in association with* A *and* B, *the melanoblasts in their autonomous growth override the inhibitory effects of* ii *and some black pigmentation is formed.*

PLATE 2

GENETICS OF ERYTHROMELANOMAS


DrSp st/DrSp st
PLATYFISH
RtSb St/RtSb St
X
8
9
Drsp st/Drsp st
DrSp st/RtSb St
X
11
10
Drsp st/DrSp st
Drsp st/DrSp St
Drsp st/RtSb St
12
13
14
SWORDTAIL
PLATYFISH
SWORDTAIL
GOLDEN ALBINO
PLATYFISH
Drsp st/RtSb st

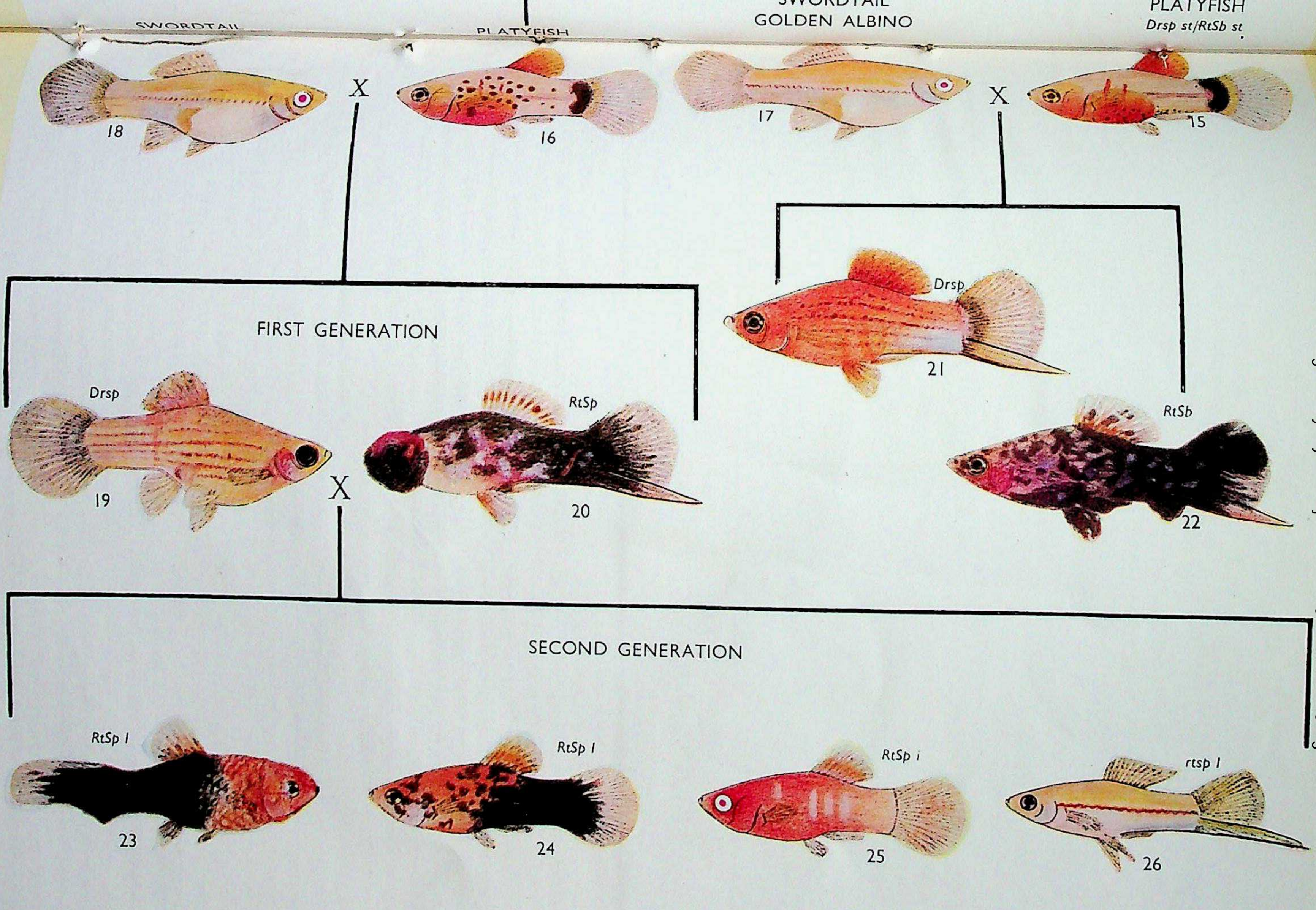

SWORDTAIL
PLATYFISH
SWORDTAIL
GOLDEN ALBINO
PLATYFISH
Drsp st/RtSb st
18
X
16
17
X
15
FIRST GENERATION
Drsp
21
RtSb
22
Drsp
19
X
RtSp
20
SECOND GENERATION
RtSp I
23
RtSp I
24
RtSp i
25
rtsp I
26

FIGURE 8 – *Golden, red-dorsal-finned, black-spotted platyfish, female.* FIGURE 9 – *Stippled, ruby-throated, spotted-bellied platyfish, male.* FIGURE 10 – *Stippled, red-dorsal-finned, black-spotted, ruby-throated, spotted-bellied platyfish, male.* FIGURE 11 – *Golden, red-dorsal platyfish, female.* FIGURE 12 – *Golden, red-dorsal, spot-sided platyfish, male.* FIGURE 13 – *Stippled, red-dorsal, spot-sided platyfish, male.* FIGURE 14 – *Stippled, red-dorsal, ruby-throated, spotted-bellied platyfish, male.* FIGURE 15 – *Golden, red-dorsal, ruby-throated, spotted-bellied platyfish, male.* FIGURE 16 – *Golden, red-dorsal, ruby-throated, spot-sided platyfish, male (exceptional).* FIGURE 17 – *Golden albino swordtail, female.* FIGURE 18 – *Golden albino swordtail, female.* FIGURE 19 – *Golden, red-dorsal platyfish-swordtail hybrid, normal female.* FIGURE 20 – *Golden, ruby-throated, spot-sided hybrid male with erythromelanoma of the head.* FIGURE 21 – *Golden, red-dorsal platyfish-swordtail hybrid, normal.* FIGURE 22 – *Golden, ruby-throated, spotted-bellied hybrid with melanoma of the mid-ventral line.* FIGURE 23 – *Second generation hybrid with erythromelanoma of the head.* FIGURE 24 – *Second generation hybrid showing melanosis, may develop erythromelanoma when older.* FIGURE 25 – *Second generation hybrid albino showing inhibition of melanin pigment. The xantho-erythrophores are not inhibited.* FIGURE 26 – *Second generation hybrid, golden swordtail-like hybrid, normal male.*

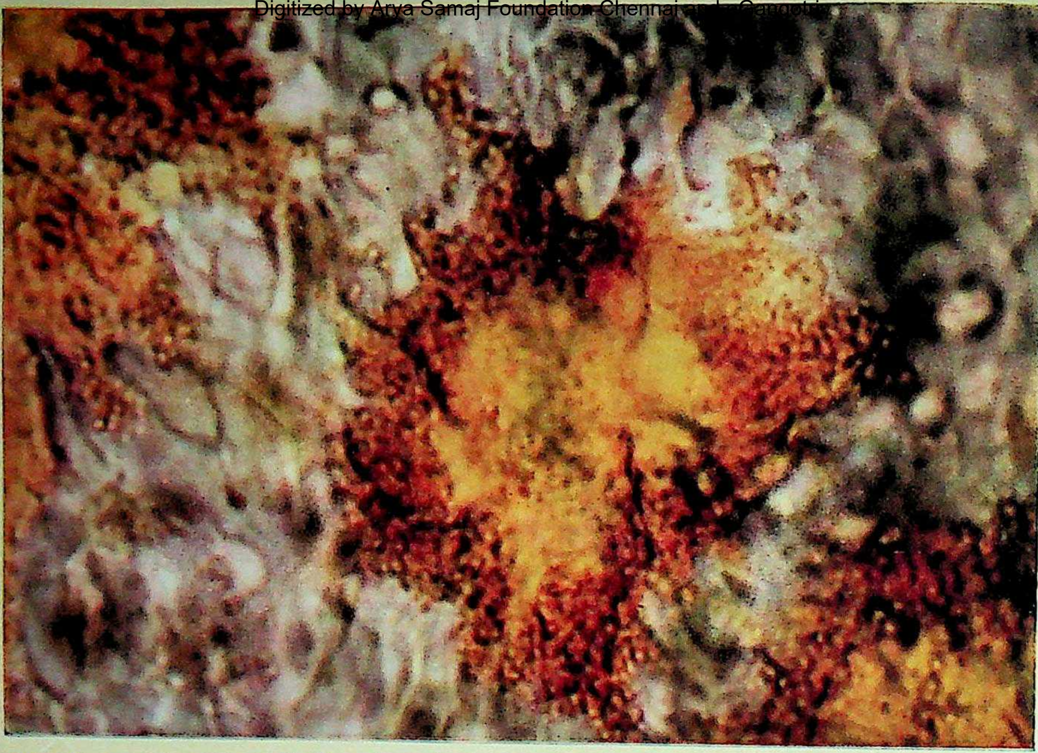


FIGURE 27 – *A xantho-erythrophore from* Xiphophorus hellerii. *Photograph of living cell taken by Marian Hedenberg. By courtesy of Dr H. B. Goodrich.* (× 1350)

'allophoroma' in a gurnard, were discovered [31, 32]. In Europe, a xanthoma was reported but once, in a shark [28]. Four erythrophoromas have been discovered among wild fish: in two European trout and a tunny, and in an American winter flounder [29, 33]. Again, in the aquarium-reared fish three erythrophoromas have been detected in the dorsal fin region of golden, red-finned platyfish-swordtail hybrids, and one in a black-spotted red hybrid [8, 22, 30].

Taken all together, the number of red and red-black tumours described in all fishes is only eight. This is exactly the number of cases of red-black tumours that we discovered in one single brood of hybrids born from the mating of a uniquely coloured black-spotted, red platyfish and an albino swordtail (plate 2). Because of the high frequency of these erythromelanomas, the genetic history of the animals was analysed. Before describing our results it would be advantageous to indicate the specific role of the macromelanophores in the development of melanomas in platyfish-swordtail hybrids.

The freshwater Mexican platyfish, *Platypoecilus maculatus*, has more than a hundred black patterns. These are formed from two kinds of melanophore, one large, one small, which are variously arranged upon the body. The *micromelanophores* (controlled by gene *St*) cover the entire surface, and these, together with the underlying xanthophores, give the fish an olive-green grey coloration. The *macromelanophores* (controlled by gene *Sp*) are visible to the naked eye, and these give the fish a spotted appearance.

In a long series of genetic experiments with variously coloured platyfish and swordtails, the *macromelanophore* (*Sp*) was discovered to be the initiating cell in the development of melanomas in the hybrids [16, 17, 18]. The crucial experiment depended upon getting, first, a pure-bred platyfish with macromelanophores (*Sp*) but with no micromelanophores (*stst*) and, second, a swordtail with no melanophores at all (*spsp stst*). A pink-eyed albino swordtail (*ii*) visibly free of melanophores was available, but it was discovered, by testing, that it carried the dominant genetic factor for micromelanophores (*StSt*), the melanin-producing *St* gene being inhibited by the *ii* gene. After some preliminary work a special stock of albinos was developed which was recessive both for micromelanophores and for albinism (*stst ii*). A female albino swordtail (*stst ii*) was mated with a platyfish male carrying macromelanophores only (*stst Spsp*). This mating may be represented genetically as follows:

Albino swordtail P_1 *Macromelanophore platyfish*
stst ii spsp × *stst II Spsp*
F_1 hybrids
stst Ii Spsp: 20 were deeply black, showing hyperplastic growth of macromelanophores; many developed melanomas.
stst Ii spsp: 29 were yellow-coloured, black-eyed, normal.

This experiment shows that the macromelanophores alone may initiate melanomas in platyfish-swordtail hybrids.

The genetic history of the erythromelanomas which developed in a significant proportion of a single brood of platyfish-swordtail hybrids was traced to a mating between an exceptionally coloured male platyfish and an albino swordtail female. The male platyfish, which had an unusual combination of colour genes, *Rt* for ruby-throated and *Sp* for spot-sided pattern, was obtained as a by-product from a routine series of studies on the genetic mechanisms for sex determination in fish. In that analysis a mating was arranged between two pure-breeding domesticated strains of platyfish [14, 15].

The male grandparent of the exceptional *RtSp* platyfish had the following genes and their corresponding colour patterns (plate 2):

Rt (*ruby-throat*), a sex-linked gene for xanthoerythrophores, an allele of *Dr* (*red dorsal*).
Sb (*spotted belly*), a sex-linked gene for macromelanophores, an allele of *Sp*.
St (*stipple*), an autosomal gene for micromelanophores producing grey body colour.

The female grandparent of the *RtSp* platyfish had the following genes and their corresponding colour patterns:

Dr (*red dorsal fin*), a sex-linked gene for xanthoerythrophores, an allele of *Rt* [11].
Sp (*spotted sides*), a sex-linked gene for macromelanophores, an allele of *Sb* [11].
st, the recessive *stipple* gene producing golden body colour, an allele of *St* [13, 16].

Thus the mating between the red-finned, black-spotted female platyfish and the ruby-throated, spotted-belly male may be represented as follows, where the W indicates a strong female-determining chromosome and the Y indicates the male-determining chromosome in domesticated platyfish stocks [15] (mating number 1; plate 2, figures 8 and 9):

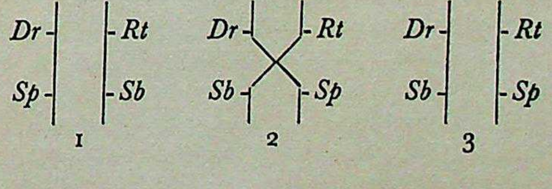
Female P_1 *Male*
(W)*DrSp st*/(Y)*DrSp st* × (Y)*RtSb St*/(Y)*RtSb St*
F_1 Pedigree No. 104
24 daughters: (W)*DrSp st*/(Y)*RtSb St*.
19 sons: (Y)*DrSp st*/(Y)*RtSb St* (plate 2, figure 10).

One of the F_1 males (culture no. 104) was selected and mated to a golden red-finned female of a strain that was homozygous for the *st* and *Dr* genes. This female had two X chromosomes characteristic of the wild platyfish. When a *wild* XX female is mated with a *domesticated* YY male it produces sons but no daughters [15].

The results obtained in the second mating may be expressed genetically as follows (plate 2, figures 10 and 11):

Female P_1 *Male*
(X)*Drsp st*/(X)*Drsp st* × (Y)*DrSp st*/(Y)*RtSb St*
F_1 Pedigree No. 173
28 males: (X)*Drsp st*/(Y)*DrSp St*, red dorsal; spotted sides; olive body colour (figure 13).
13 males: (X)*Drsp st*/(Y)*DrSp st*, red dorsal; spotted sides; golden body colour (figure 12).
32 males: (X)*Drsp st*/(Y)*RtSb St*, red dorsal; ruby throat; spotted belly; olive body colour (figure 14).
20 males: (X)*Drsp st*/(Y)*RtSb st*, red dorsal; ruby throat; spotted belly; golden body colour (figure 15).
1 male: (X)*Drsp st*/(Y)*RtSp st*, *exceptional cross-over*; red dorsal; ruby throat, spotted sides; golden body colour (figure 16).

The presence of a single exceptional *Drsp st*/*RtSp st* male out of a brood of 94 platyfish may be accounted for by a chance crossing-over of the Y chromosomes of its male parent, which produced a gamete containing the *Rt* and *Sp* genes by a method suggested below:



Crossing-over of the platyfish sex chromosomes, previously reported, occurs at the rate of 1 per cent. [11, 14, 15].

The exceptional ruby-throated, spot-sided *RtSp st*/*Drsp st* male (pedigree no. 173–15) was used in two experiments. It was first mated with an albino swordtail which was recessive for albinism (*ii*) and for golden (*stst*) indicated as follows: *st i*/*st i* [18]. Since the platyfish, as well as the swordtail, was recessive for golden, the gene *stst* will not be indicated further. *A* and *B* in the albino (see below) represent postulated dominant multiple factors which modify the normal growth pattern of macromelanophores represented by the *Sp* gene [17]. Mating number 3 is as follows (plate 2, figures 16, 18):

Swordtail Female (182–1) P_1 *Platyfish Male* (173–15)
Albino — Red-finned, ruby-throated spotted sides
A B drsp i/*A B rtsp i* × *a b Drsp I*/*a b RtSp I*
F_1 Pedigree No. 206
18 *A B drsp i*/*a b Drsp I*, red platyfish-swordtail hybrids, normal (figure 19).
14 *A B rtsp i*/*a b RtSp I*, melanotic hybrids, 8 *of which developed erythromelanomas* of the head at two years or more of age (figure 20).

The same exceptional *RtSp st* platyfish male (no. 173–15) was later mated with a golden platyfish (*rtsp st*) of a closely related domesticated strain. This mating (number 4) produced 26 offspring, 11 of which were phenotypically *RtSp st* yet none was abnormal and, of course, the 15 recessive *rtsp st* were normal as well. Subsequent matings within these domesticated (*RtSp st*) platyfish lines have not yet produced any abnormally pigmented individuals in over 300 fishes reared to maturity. Thus the pathological platyfish-swordtail hybrid individuals of culture number 206 must have been produced by the peculiar linked combination of the *RtSp* colour genes of the platyfish with the colour gene modifiers *A* and *B* of the albino swordtail.

When a platyfish-swordtail hybrid male (206–12) with an erythromelanoma of the head was mated to its normal female sibling (206–1) they produced 102 second generation offspring. The results of this mating (number 5) may be represented as follows (plate 2, figures 19, 20, 23, 24, 25, 26):

Female Hybrid (206–1) — *Male Hybrid* (206–12)
Red, normal — Erythromelanoma on head
A B drsp i/*a b Drsp I* × *A B rtsp i*/*a b RtSp I*

The number of different genotypes possible from the mating (not considering cross-over types) is more than twice the actual number of F_2 hybrids reared. For this reason a detailed genetic analysis of the 102 F_2 hybrids is not practicable. However, the number of *RtSp* animals expected can easily be estimated to be about 50 per cent., or 51 of the total, 102. Actually there were 53 *RtSp* hybrids, of which 11 had unmistakable signs of erythromelanomas of the head. This number (11) was short of the number (39) to be expected if the suggested combination of *RtSp A B* genes alone induces the tumours. Obviously other factors were also involved, but these could not be identified in this experiment. (For some of the phenotypes see plate 2, figures 23, 24, 25, 26.)

There is further indirect evidence that the *RtSp* linkage of genes is necessary for the development of erythromelanomas in hybrid fishes. From the same brood that produced the exceptional *RtSp* male of culture number 173, a sibling male (*RtSb*) with the usual ruby-throated, spotted-belly pattern was chosen and mated to an albino female swordtail of the same culture number as used previously. This mating number 6 may be represented as follows (plate 2):

Swordtail female (182–2) P_1 *Platyfish male* (173–13)
Albino (figure 17) — Ruby-throated, spotted belly (figure 15)
A B drsb i/*A B rtsb i* × *a b Drsp I*/*a b RtSb I*
F_1 Pedigree No. 207
14 *A B drsb i*/*a b Drsp I*, red-finned, red body, normal hybrids (figure 21).
12 *A B rtsb i*/*a b RtSb I*, all highly melanotic, seven of which developed typical melanomas of the mid-ventral areas at one to two years of age (figure 22).

It is significant that the *RtSb* combination together with *A* and *B* produces melanomas but is incapable of producing erythromelanomas. The *Sb* melanomas are usually found on the ventral areas of the body [18].

One additional experiment (mating number 7) was made in an effort to study the effect of the homozygous albino genes *ii* on the expressivity of the *RtSp* erythromelanomas by means of a backcross as follows:

Swordtail female (182^{2}–6) P_1 *Hybrid male* (206–12)
Albino — Erythromelanoma
A B rtsp i/*A B rtsp I* × *A B rtsp i*/*a b RtSp I*
The phenotypes of the offspring (culture no. 241) were as follows:
3 *RtSp i*, red-eyed albinos, 2 with amelanotic melanomas, 1 with no tumour, at six months of age, similar to those figured in plate 1, figure indicated by *RtSp i*.
7 *RtSp I*, typically melanotic, 3 with melanomas at six months of age.
7 *rtsp i*, albinos, red eyes, normal.
7 *rtsp I*, golden, black eyes, normal.

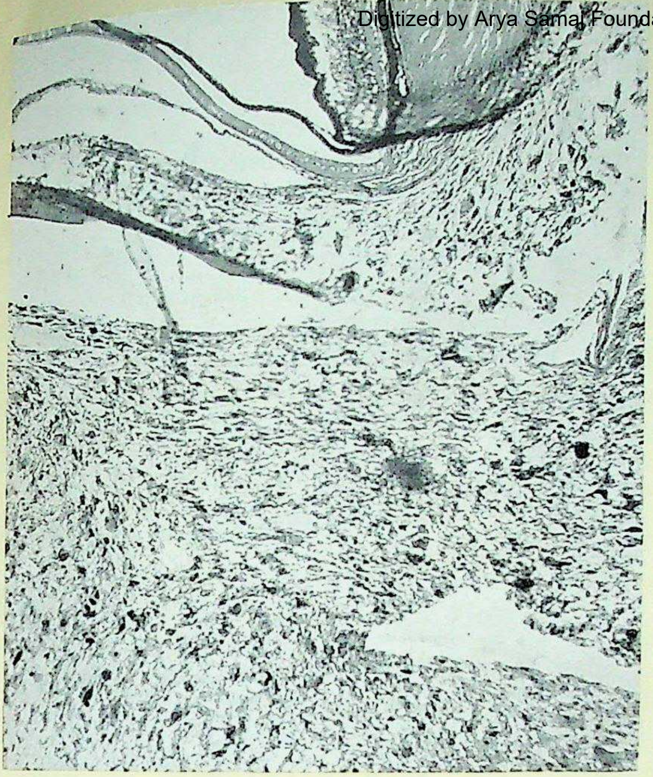


FIGURE 28 – *Cross-section of the erythromelanoma at the level of the eye, under low power. The black spots are macromelanophores and the grey bodies are erythrophores. The entire growth is supported by a well-developed connective tissue reticulum. Note the invasion of muscle, cartilage, and bone of the eye.* (*Haematoxylin and eosin,* × 110)

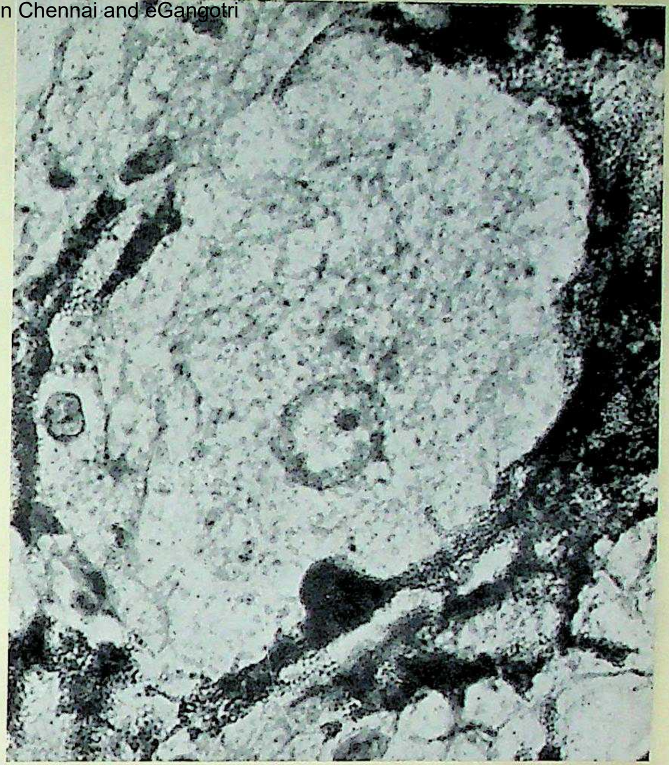


FIGURE 29 – *Cross-section through the erythromelanoma under high power, showing a large erythrophore with its nucleus. This cell is surrounded by several large macromelanophores.* (*Iron-hæmatoxylin,* × 610)

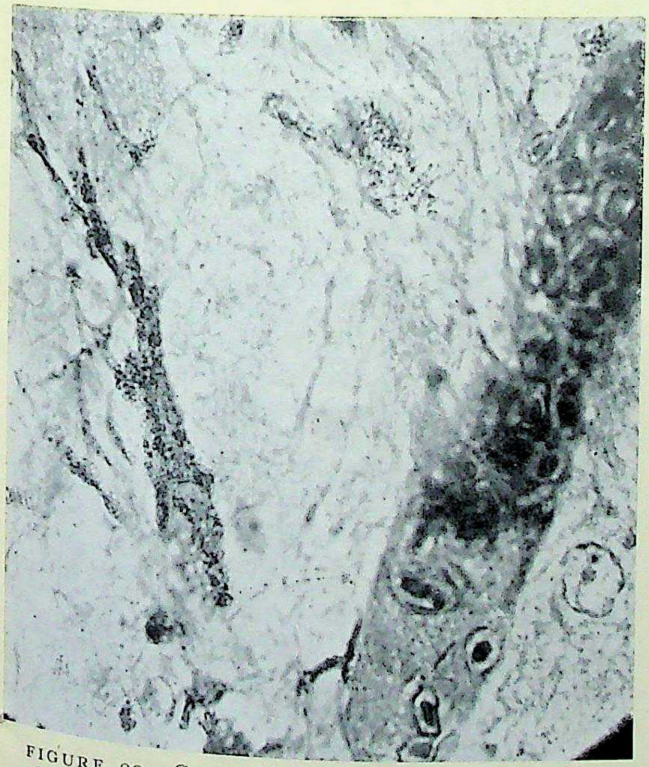


FIGURE 30 – *Cross-section through an erythromelanoma, showing blood-vessel invasion, with an erythrophore cell to the right of the blood-vessel and the highly dendritic macromelanophore to the left of the blood-vessel.* (*Masson,* × 610)

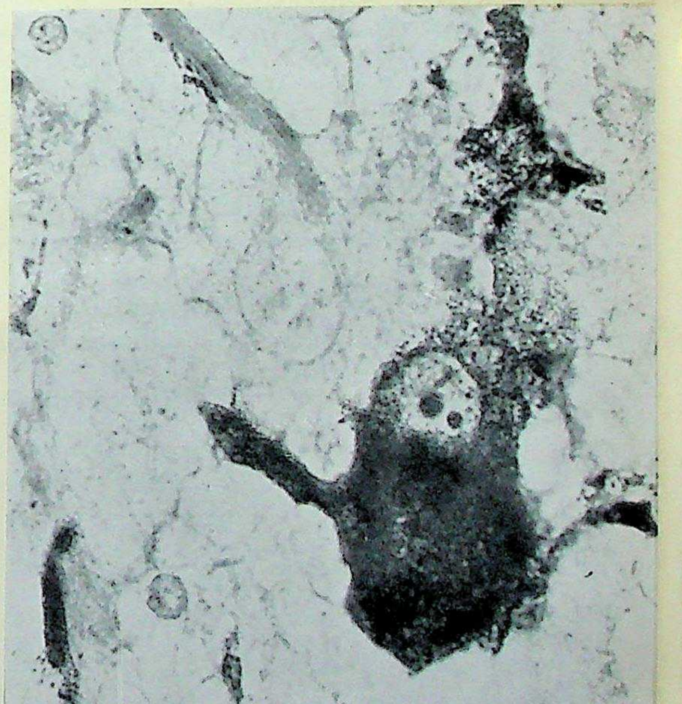


FIGURE 31 – *Cross-section through an erythromelanoma, showing in the upper left-hand corner the destruction of the muscle fibre. A macromelanophore with its nucleus lies in the centre of the figure, and the nuclei of several erythrophores are scattered at various points.* (*Masson,* × 610)

When born, the *RtSp i* hybrids had dark areas of melanin pigmentation on part of their bodies. This is quite remarkable, since they are pink-eyed homozygous recessive for the albino gene. The tumour factors, *Sp* interacting with *A* and *B*, override the albino effect [3, 4, 18]. (See plate 1, Back-cross Generation.)

A study of these genetic data reveals a significant relationship between the spatial association of genes and the effects they produce. The linkage of genes *RtSb* in the platyfish interacting with the *A* and *B* modifying genes of the swordtail determines the development of melanomas in their hybrids. The substitution of *Sp* for *Sb* to produce the *RtSp* linkage, and the introduction of this combination of genes in the platyfish-swordtail hybrid, produce erythromelanomas of the head.

If, however, the genes *Rt* and *Sp* in a platyfish were on separate sex chromosomes, then the ruby-throated, black-spotted platyfish (*Rtsp/rtSp*) when mated with an albino swordtail would produce melanomas rather than erythromelanomas. This would be so because the platyfish would be producing gametes containing *Rtsp* or *rtSp* most of the time. Occasionally the *Rtsp/rtSp* platyfish might be expected to produce an *RtSp* gamete created by a crossing-over of the sex chromosomes. Thus a situation might easily arise in which the genetic constitutions of parents are known in terms of genes involved, and yet unless the spatial relationships of the genes are known also, the results cannot be predicted with complete assurance. These details indicate the importance of studying the various genes and gene combinations and their specific effects upon the growth of specific cells.

It is a pleasure to make the following acknowledgments: to the American Museum of Natural History for laboratory facilities, to the National Cancer Institute of the United States Public Health Service for the grant which made this work possible, to Dr Ross F. Nigrelli for the photomicrographs, to Dr Nigrelli and Dr William Antipol for aid in diagnosis, to Mr Donn Eric Rosen for the drawings, to Mr Sam C. Dunton for photography, and to Mr James W. Atz, Mr Theodor R. Marcus, Mr Walter Chavin, and Miss Olga Aronowitz for reading the manuscript.

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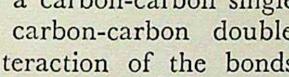
Cyclo-polyolefines and related molecules

WILSON BAKER

In this article Professor Wilson Baker describes recent developments in our knowledge of certain cyclic conjugated compounds other than those which are benzenoid in character. These include such interesting compounds as tropilone, the azulenes, and various cyclic meso-ionic substances. Recent research has shown that many of the last class of compounds had been wrongly formulated; for some, no single formula is adequate.

Benzene has been regarded as the parent hydrocarbon of the aromatic series since the beginning of systematic organic chemistry; it was originally formulated by Kekulé in 1865 as *cyclo*-hexatriene (figure 1). Seven years later, in order to avoid the difficulty of the non-existence of isomeric *ortho*-disubstituted benzenes, Kekulé suggested that the double bonds oscillated between the two possible positions. Benzene is now known to possess a single structure which may be considered as a hybrid of the two *cyclo*-hexatrienes; in this single structure the conjugated double bonds have interacted to produce six equal carbon-carbon links which have a length of 1·39 A, a value intermediate between that of a carbon-carbon single bond (1·54 A) and a carbon-carbon double bond (1·34 A). The interaction of the bonds brings about a considerable stabilization of the molecule, and calculations based either upon heat of combustion or upon heat of hydrogenation (Kistiakowsky) show that the heat of formation of benzene is some 39 kilogram calories per gram molecule more than that of the hypothetical molecule of *cyclo*-hexatriene with non-interacting double bonds.

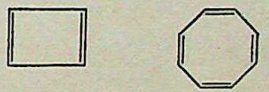


Cyclo-*hexatriene* Cyclo-*hexatriene*

Benzene

FIGURE 1

This extra heat of formation, usually referred to as the resonance energy, confers a stability on the molecule which could not be expected of *cyclo*-hexatriene. It also causes benzene to behave chemically in the majority of its reactions as a saturated compound which reacts by substitution, rather than as an olefine which normally reacts by addition. It has long been a matter for conjecture whether other cyclic conjugated olefines such as *cyclo*-butadiene or *cyclo*-octatetraene (figure 2) would possess the typical aromatic characteristics of stability and a high degree of saturation, and it is now seen that, if so, the double bonds of the conjugated systems must be capable of a high degree of resonance interaction. It is, moreover, an essential for resonance that the molecule should be planar; this is because the forms which may be regarded as contributing to the hybrid must possess almost exactly the same relative positions of the atoms, and if, for reasons of strain, this is not possible, then the molecule will not be aromatic but will behave as a *cyclo*-polyolefine. The conditions for resonance are clearly fulfilled by *cyclo*-hexatriene, which becomes the single molecule of benzene.



Cyclo-*butadiene* Cyclo-*octatetraene*

FIGURE 2

In the case of *cyclo*-butadiene, although the molecule would in any case be expected to be flat, the internal angles of 90° are far from the natural $C{=}C{-}C$ angles of 120°, and the strain thus set up might more than compensate for the resonance energy. *Cyclo*-butadiene cannot, therefore, be expected to exhibit aromatic characteristics, and may indeed be too unstable to exist.

The molecule of *cyclo*-octatetraene, if planar, would require internal angles of 135°, so that considerable strain would be set up, and a position of compensation is doubtless reached when a further gain in stability due to resonance is offset by a decrease in stability due to strain.

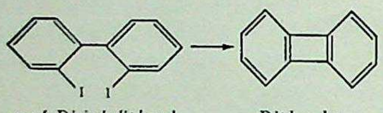
It is the object of the present article to describe some of the recent developments in our knowledge of certain cyclic conjugated compounds other than those which are formally benzenoid in character.

CYCLO-BUTADIENE AND DIPHENYLENE

Early attempts by Willstätter [1] to prepare *cyclo*-butadiene by removal of hydrogen bromide from 1:2-dibromo*cyclo*butane resulted in the production of acetylene, open-chain compounds, and

-1-bromo*cyclo*butene-1. A more ambitious attempt by Buchmann in 1942 [2] involved the exhaustive methylation of 1:2-di-dimethylamino*cyclo*butane, but the products were all derivatives of either *cyclo*-butane or *cyclo*-butene. The conclusion may be drawn from these experiments that *cyclo*-butadiene is unlikely to be a stable compound of aromatic character, and this is consistent with the considerations already set out.

The only known compounds which may be regarded as derivatives of *cyclo*-butadiene are the remarkably stable diphenylenes (figure 3). Diphenylene itself was prepared by Lothrop in 1941 [3] by heating a mixture of 2:2′-di-iododiphenyl with cuprous oxide, and homologues were prepared in a similar manner.



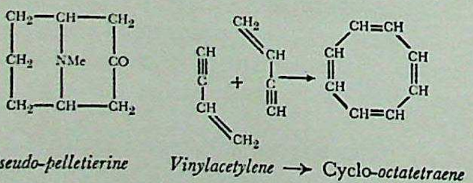
2:2′-Di-iododiphenyl *Diphenylene*

FIGURE 3

Diphenylene crystallizes in pale yellow prismatic needles, m.p. 110°, and readily forms a scarlet picrate. Owing to its inaccessibility, its chemical properties have been little investigated, but on catalytic reduction in alcoholic solution in presence of Raney nickel it gives diphenyl in high yield, thus indicating a considerable strain in the four-membered ring. Diphenylenes are the only compounds known which possess a four-membered ring fused to an aromatic nucleus.

CYCLO-OCTATETRAENE AND DERIVATIVES

Cyclo-octatetraene was first prepared by Willstätter in 1911 [4] from the alkaloid pseudo-pelletierine (figure 4), which contains a bridged *cyclo*-octane ring. Many steps, not all of an unambiguous character, were involved in the preparation, and the final product, a yellow, unstable, unsaturated hydrocarbon, C_8H_8, was not universally accepted as being *cyclo*-octatetraene. This synthesis from pseudo-pelletierine has, however, recently been repeated [5], and Willstätter's work was confirmed in all essentials.

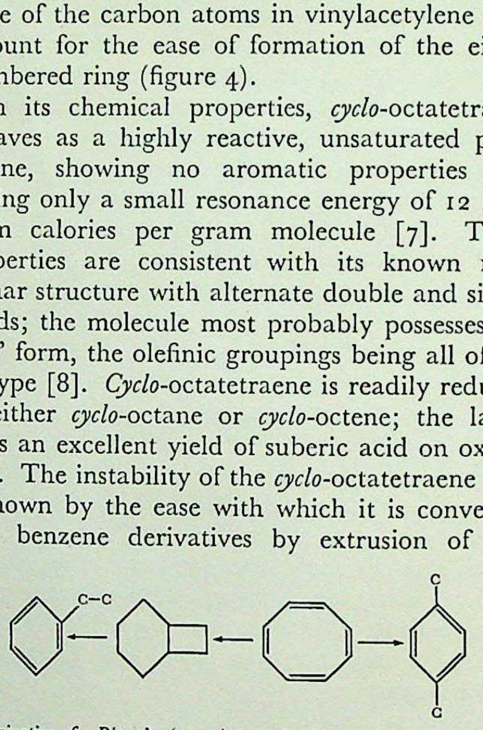


Pseudo-pelletierine *Vinylacetylene* → Cyclo-*octatetraene*

FIGURE 4

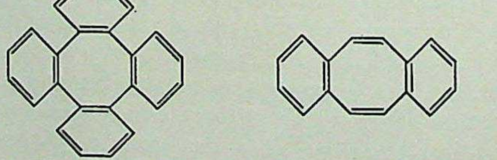
A very remarkable synthesis of *cyclo*-octatetraene was achieved by Reppe [6] in the course of an extensive investigation of the synthetical possibilities of acetylene. Reppe showed that acetylene could be safely handled on a large scale, in specially constructed apparatus, under pressures of up to thirty atmospheres, and found accidentally, during an attempt to effect its combination with ethylene oxide, that at 10–20 atmospheres in tetrahydrofuran, in presence of nickel cyanide, it gave *cyclo*-octatetraene in over 70 per cent. yield. With regard to the production of *cyclo*-octatetraene rather than benzene, it is tempting to suggest that it may result from the dimerization of vinylacetylene on the catalyst surface; the linear arrangement of three of the carbon atoms in vinylacetylene may account for the ease of formation of the eight-membered ring (figure 4).

In its chemical properties, *cyclo*-octatetraene behaves as a highly reactive, unsaturated polyolefine, showing no aromatic properties and having only a small resonance energy of 12 kilogram calories per gram molecule [7]. These properties are consistent with its known nonplanar structure with alternate double and single bonds; the molecule most probably possesses the 'tub' form, the olefinic groupings being all of the *cis* type [8]. *Cyclo*-octatetraene is readily reduced to either *cyclo*-octane or *cyclo*-octene; the latter gives an excellent yield of suberic acid on oxidation. The instability of the *cyclo*-octatetraene ring is shown by the ease with which it is converted into benzene derivatives by extrusion of two carbon atoms to give derivatives of either ethylbenzene or *p*-xylene. An example of the former type is its immediate conversion by aqueous



Derivative of ethylbenzene Bicyclo-(0:2:4)-*octane* Cyclo-*octatetraene* *Derivative of* p-*xylene*

FIGURE 5

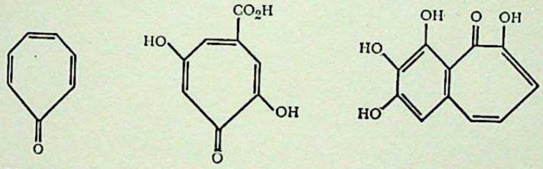


Tetraphenylene Symm.*dibenz*cyclo-*octatetraene*

FIGURE 6

mercuric sulphate into phenylacetaldehyde, and an example of the latter type is the formation of terephthalaldehyde by treatment with alkaline hypochlorite. *Cyclo*-octatetraene is also converted into derivatives of bi*cyclo*-(0:2:4)-octane, for example by the action of chlorine or sulphuryl chloride, and this bicyclic type may be involved in the formation of derivatives of ethyl benzene (figure 5).

Tetra- and tribenz*cyclo*-octatetraenes have been prepared [9]; the former has a buckled eight-membered ring [10], which does not contribute to the ultra-violet absorption of the molecule, and appears to be merely a hole enclosed by the four benzene rings; indeed, its alternative name, tetraphenylene, conveys a more accurate picture of its structure. In symmetrical dibenz*cyclo*-octatetraene [11], the eight-membered ring shows no aromatic properties, the two —CH:CH— groups exhibiting the usual olefinic unsaturated character (figure 6).



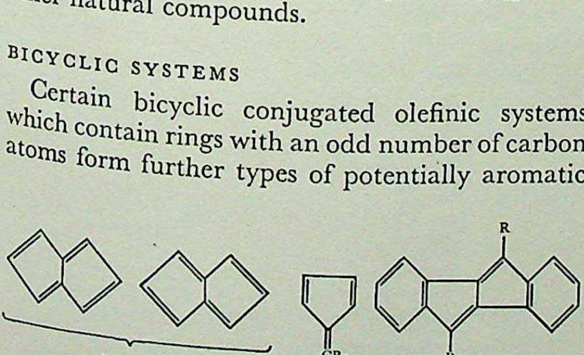
Tropilone *Stipitatic acid* *Purpurogallin*

FIGURE 7

A very interesting type of molecule which is partially aromatic in character has recently attracted considerable attention. This is represented by the substance tropilone (figure 7), which contains three conjugated double bonds in a seven-membered ring, in conjugation with a carbonyl double bond outside the ring. This structure probably occurs in stipitatic acid [12], in the alkaloid colchicine [13], in purpurogallin (an oxidation product of pyrogallol) [14], and other natural compounds.

BICYCLIC SYSTEMS

Certain bicyclic conjugated olefinic systems which contain rings with an odd number of carbon atoms form further types of potentially aromatic compounds. The simplest of these, pentalene, is unknown, but would consist of two fused five-membered rings [15] (figure 8); it should satisfy the conditions previously set out as necessary for the possession of aromatic properties. Two identical Kekulé-like structures are possible; these would be planar and not highly strained, and they bear a close resemblance to the fulvenes, which contain a conjugated system of two cyclic and one exocyclic double bond and are, so far as is known, only weakly aromatic in character. It seems improbable, however, that simple pentalenes would possess a high degree of aromatic character, because attempts to effect dehydrogenation of 0:3:3-bi*cyclo*-octane (octahydropentalene) were unsuccessful [16] under reaction conditions which readily brought about the conversion of decalene into naphthalene. The only derivatives of pentalene yet described are a few dibenzopentalenes (figure 8, where R stands for Cl or Ph) [17], and it seems that in these compounds the pentalene system is stabilized by fusion with the benzene rings, just as the *cyclo*-butadiene ring is stabilized in diphenylene. Benzopentalene (*cyclo*-pentindene) is isomeric with diphenylene, but has not yet been prepared [18].

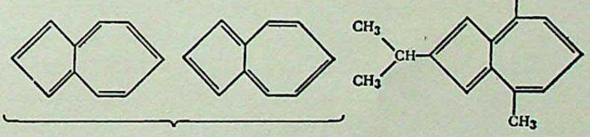


Pentalene *A Fulvene* *Dibenzopentalenes*

FIGURE 8

THE AZULENES

These interesting hydrocarbons are closely analogous to the pentalenes, and possess fused five- and seven-membered rings (figure 9) [19].



Azulene *Vetivazulene*

FIGURE 9

As with the pentalenes, two Kekulé-like structures are possible, and the molecule may be flat and not highly strained. The azulenes have long attracted attention on account of their intense colour, which is usually blue or violet. For example, a 0·1 per cent. solution of azulene itself in a hydrocarbon solvent possesses a fairly deep pure blue colour, so that the minutest traces are at once detectable. Were the azulenes colourless, it is doubtful if we should possess any knowledge of them. Azulenes have been isolated from certain essential oils, and have been prepared by high-temperature dehydrogenation from colourless hydrogenated derivatives contained in the oils; they have also been prepared by dehydrogenation of synthetic compounds containing the reduced azulene skeleton (derivatives of 0:3:5-bi*cyclo*-decane).

The yields of azulenes obtained by the final dehydrogenations are very small, and these hydrocarbons remain chemical curiosities which have seldom been handled in quantities of more than a few milligrams. Their isolation from both aliphatic and ordinary aromatic compounds is fortunately an easy matter, owing to the fact that they are soluble in 85 per cent. phosphoric acid to give solutions from which the azulene is regenerated by dilution with water [20]. Our knowledge of the chemical behaviour of the azulenes is slight, but it is clear that they possess considerable stability, and like the polycyclic aromatic hydrocarbons they form complexes with reagents such as picric acid and 1:3:5-trinitrobenzene. The resonance energy of the azulene system is 46 kilogram calories per gram molecule [21], compared with the value of 77 kilogram calories for naphthalene, with which it is isomeric.

The structure of the azulenes has been established both by controlled degradation to derivatives of *cyclo*-pentane and *cyclo*-heptane, and by synthesis. Methods employed to build up the reduced azulene ring system have included enlargement of the benzene ring in derivatives of indane by the use of diazoacetic ester, and the Demjanov procedure, whereby a *cyclo*-hexylmethylamine is converted into a derivative of *cyclo*-heptane by the action of nitrous acid. More routine methods of building up the seven-membered ring on to the five-membered ring and *vice versa* have also been employed. The simplest azulene synthesis yet recorded is its production in small quantity by the polymerization of acetylene (Reppe). The naturally occurring azulenes are simple alkyl derivatives of the parent compound; thus vetivazulene is the dimethyl*iso*propyl-azulene shown in figure 9.

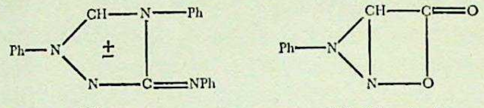
A further possible aromatic system allied to azulene is that consisting of two fused seven-membered rings with six double bonds, but this compound, heptalene, is as yet unknown.

CYCLIC MESO-IONIC COMPOUNDS

The reagent nitron (figure 10; see later for the meaning of the symbol ±) was probably the first to be recognized as belonging to a type of partially aromatic conjugated compound [22], to which the name meso-ionic has since been applied. The general characteristics of this type of compound have been discussed in connection with the structure of the 'sydnones,' a class of compound which was prepared by Earl and his collaborators in the University of Sydney [23]. It was found that the N-nitroso-N-arylglycines,

$$Ar.N(NO).CH_2.CO_2H,$$

gave stable, crystalline, unimolecular anhydro-compounds by loss of one molecule of water when treated with acetic anhydride, and these sydnones were soluble in hydrocarbon and other solvents.



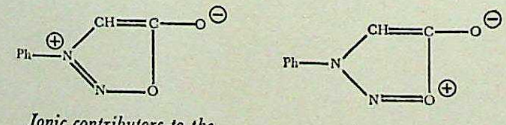
Nitron

N-*Phenylsydnone* (*bicyclic structure*)

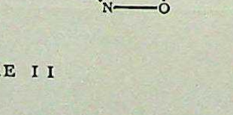
FIGURE 10

Hydrolysis with hot alkali regenerated the N-nitroso-N-arylglycines, but boiling with acids caused decomposition to carbon dioxide, formic acid, and an arylhydrazine. The sydnone derived from N-nitroso-α-anilinopropionic acid was similar, but gave acetic acid, carbon dioxide, and phenylhydrazine on hydrolysis. A bicyclic structure (figure 10) was originally tentatively suggested for the sydnones, but, apart from general objections, this formulation is inconsistent with certain facts [24]. The more important of these are that the sydnones do not behave like β-lactones; that optically active sydnones cannot be prepared [25], thus indicating that the CH or CR group is not asymmetrical; that the benzene ring in N-phenylsydnone is chemically inert and thus behaves as if it were attached to a positively charged, rather than to a neutral, nitrogen atom; and finally that the dipole moments of the sydnones are high, being for example 6·6 Debye units in the case of N-phenylsydnone.

There is no possible wholly covalent formula which satisfactorily represents the structures of the sydnones, and their physical properties exclude the possibility that they might be zwitterions



Ionic contributors to the hybrid sydnone molecule (above, left and right)



Sydnone molecule (right), showing symbol to represent their meso-ionic nature

FIGURE 11

with fixed positive and negative charges. An alternative structure has therefore been put forward, in which the electrons of the bridge bond are distributed among the atoms of the sydnone ring, thus giving rise to a single structure which cannot adequately be represented by any one formula employing conventional symbols. The molecule is, in fact, a resonance hybrid, just as benzene is essentially a resonance hybrid of the two Kekulé structures, but in this case it is a hybrid of a large number of contributing forms, all of which are of dipolar or tetrapolar character. Two of these contributors, perhaps the most important, are shown in figure 11, and the symbol ± indicating the nature of the molecule is also shown. The name meso-ionic is intended to convey the idea that the structure is intermediate between a number of ionic forms. Dipole-moment measurements of sydnones have shown [26] that the nitrogen atom attached to the phenyl group bears a large fractional positive charge, and that the negative end of the dipole is directed towards the oxygen atom of the carbonyl group.

Meso-ionic compounds such as the sydnones belong to a rare type of molecule which cannot be represented, even approximately, by a single covalent structure; or, as in the case of benzene, as a hybrid of a few covalent forms; or, as in the case of the amides, as a hybrid of a covalent and an ionic form, $—\overset{\overset{\displaystyle O}{\|}}{C}—NH—$ and $—\overset{\overset{\displaystyle O^-}{|}}{C}=\overset{+}{N}H—$. The closest analogies are provided by the aliphatic diazo-compounds, which are hybrids of two zwitterion forms $>C=N^+=N^-$ and $>C^-—N^+\equiv N$, and the organic azides, which are similarly hybrids of the two forms $R—N=N^+=N^-$ and $R—N^-—N^+\equiv N$. The cyclic meso-ionic compounds are stabilized by resonance, and may therefore be said to be partly aromatic in character, and it may be noted that, for example in the case of the sydnones, many of the contributing ionic forms are very closely allied to partially aromatic five-membered ring compounds such as furan, pyrrole, and oxazole. This aromatic character is reflected in the general properties of the sydnones, in their resistance to catalytic reduction, and in the fact that those with a free CH group undergo substitution as if this group were part of a benzene ring. The aryl group united to the heterocyclic ring is not an essential feature of the sydnone molecule, since both N-benzylsydnone and N-*cyclo*-hexylsydnone are typical members of the class.

There are other types of cyclic meso-ionic compounds in chemical literature, but they have generally been formulated as containing bridged or 'endo' five-membered rings, the majority of which are stereochemically impossible [24].

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The future of English building-stones

W. J. ARKELL

One of the features of British architecture most striking to the visitor from overseas is the dignity of the age-old stone churches, colleges, houses, and cottages. Modern methods of building, with mass-produced bricks and concrete blocks, threaten to extinguish building in stone, which for centuries has been one of Britain's proudest activities. Dr Arkell explains how scientific investigation may assist to preserve it in spite of such severe competition.

On 17th January, 1949, in London, the Minister of Health pledged himself to co-operate in every way to revive building in stone, which he acknowledged to be 'one of England's most ancient and important activities.' 'It would be a national misfortune if all our building in stone ceased,' he declared; and in the stone districts 'it would be a monstrous outrage to have the red rash of some of the industrial brick.'[1]

Many people in less influential positions have been saying the same thing for many years, but still the costs of stone building rise and still the drain of masons into occupations with better prospects continues. In Oxford and Cambridge, where war-time arrears of repair to stonework and some new buildings have to be undertaken, the colleges have to find several times the money that the same work would have cost before the war.

Yet, notwithstanding the ministerial declarations just quoted, a statement issued on 1st June, 1949, by the council of the Royal Institute of British Architects[2] shows that the real cause of the trouble is Government policy, 'which has, up to now, concentrated on economy in money costs' in house-building, at a time when house-building is given Government priority and almost all other building is held up in consequence. 'True economy,' the statement continues, 'may well dictate a much greater use of stone in state-aided housing.' . '. . . architects have no intention of abandoning the use of stone as a building material' and 'affirm their confidence in the future of the masons' craft.'

There are dangers inherent in a too sudden expansion of stone building. Really durable freestones are by no means common or easy to locate and identify even in stone districts, and long experience is necessary if disasters are to be avoided. The medieval cathedrals and churches which have successfully weathered so many centuries are built of stones that must have been subjected to ruthless selection by masons and quarrymen with lifelong experience. What may happen if short cuts are taken is exemplified by many Oxford colleges and churches built in the seventeenth and eighteenth centuries of local Headington stone. Within a century they crumbled away, and hundreds of thousands of pounds have had to be spent in re-facing them. A similar mistake was made again in the late nineteenth century, when many new buildings were put up in Oxford of another local stone from Milton near Burford. The University church of St. Mary's had to be re-faced and partly rebuilt at great cost twice in forty years, on account of the failure of Milton stone. Yet Milton quarries are close to the famous quarries of Taynton, which yielded stone of great renown for many centuries, and much that still stands in Oxford in structures 500–600 years old. The same happened with Doulting stone from Somerset. The medieval masons knew how to select Doulting stone—for instance for the west front of Wells Cathedral—that would last for 600–700 years; but much Doulting stone from adjacent quarries sent to Oxford between 1870 and 1900 is already badly decayed and will soon need replacement.

The first lesson to be learned is that bedded building stones are so variable in their capacity to resist the weather that, despite identity of geological age and all visible characteristics, it is not good policy to build with stone from random selection on the outcrop of a famous stone bed, or even from quarries close to a celebrated quarry; only the original bed in the original quarry, discovered by the old craftsmen and tested by time, is good enough. Even within a single quarry there are generally important variations in the character

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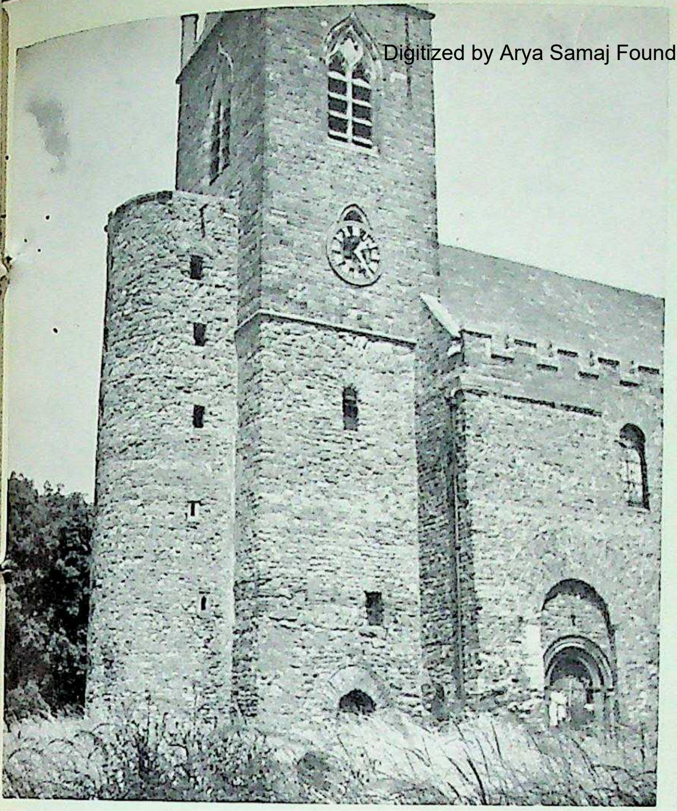

FIGURE 1 – *Saxon tower at Brixworth, Northamptonshire, probably built before* A.D. 700. *A virtually everlasting tower built of hard boulders sorted out of the local Glacial Drift, mixed with local ragstone slabs, but without freestone dressings. Except for the pulling down and rebuilding of the upper stage, the tower has had no major repairs. It is a museum of rock types, largely brought by ice from Charnwood Forest.*

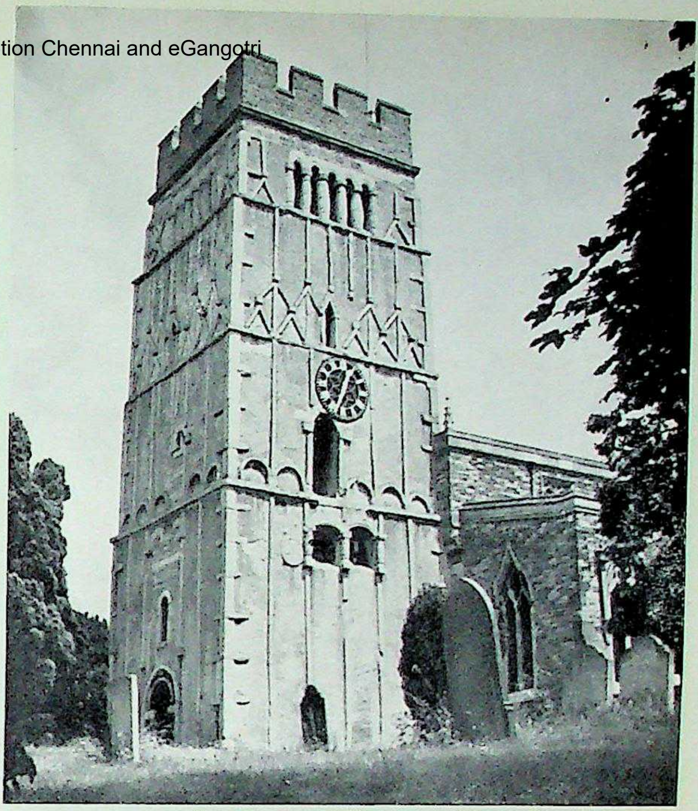

FIGURE 2 – *Saxon tower, Earls Barton, Northamptonshire, constructed from random rubble and dressed with hard Barnack Rag, brought about forty miles up the River Nene from the quarries near Stamford. An example of an almost indestructible building which has lasted a thousand years, built without any freestone.*

The pilaster strips are structural ties strengthening the random rubble walls. Some of the ornamental work may be in imitation of wooden construction.

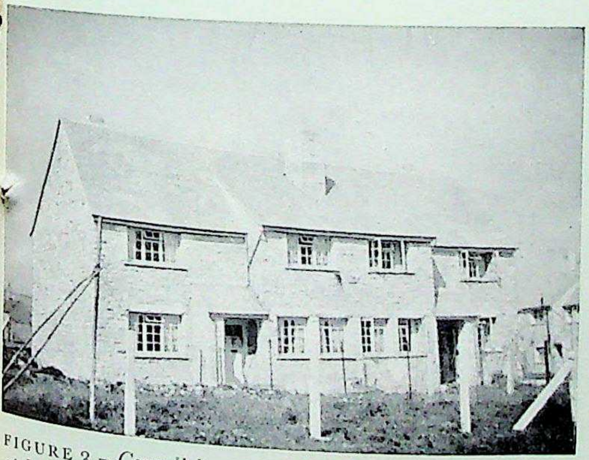

FIGURE 3 – *Council houses, built of the local walling-stone, at Langton Matravers, Isle of Purbeck.*

(*By permission of the editor of* Mercury)

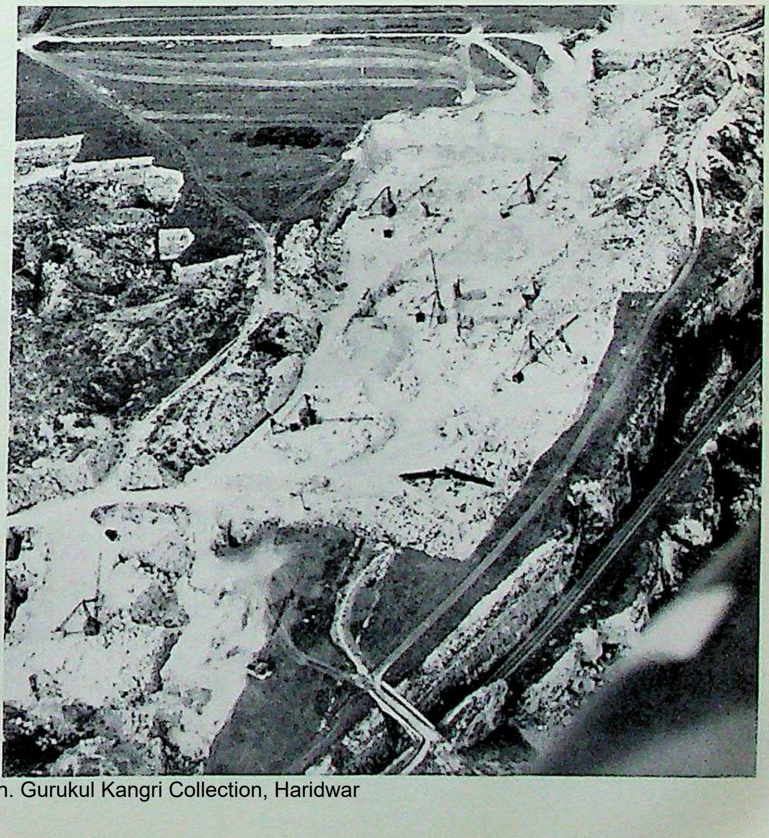

FIGURE 4 – *Some of the Portland stone quarries from the air.*

(*By permission of Dr J. K. St. Joseph*)

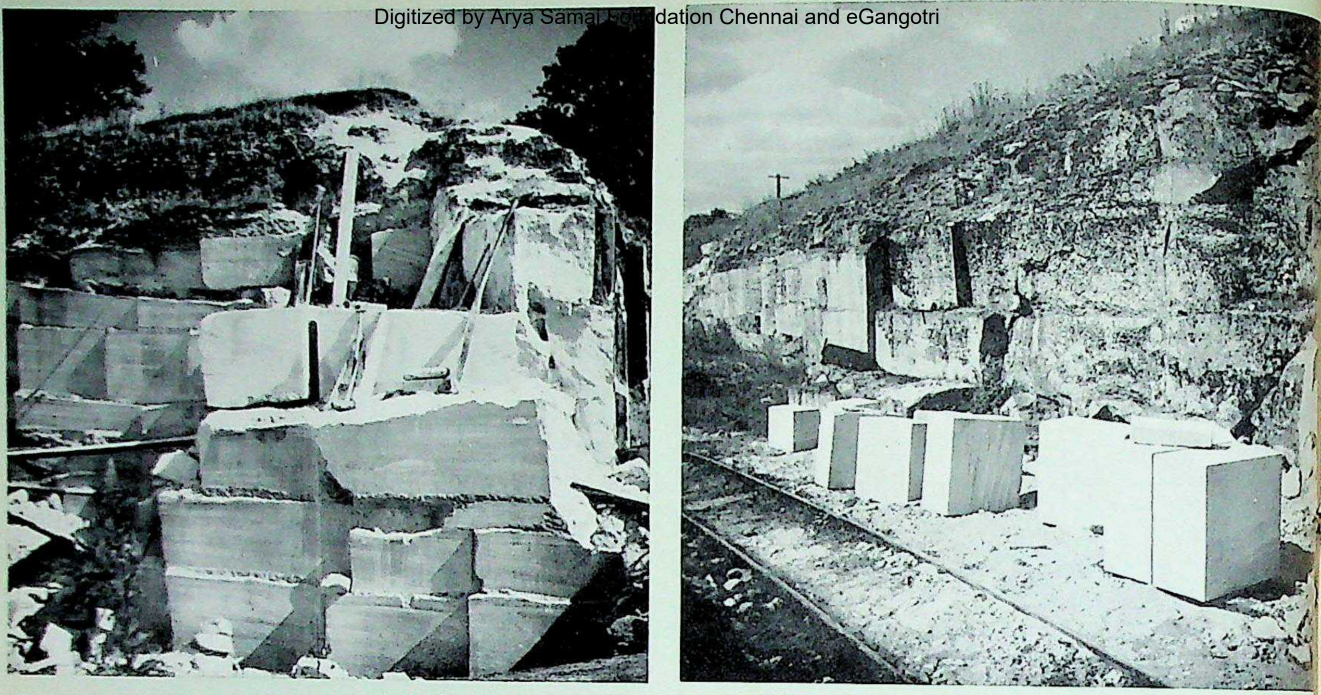

FIGURE 5 – (*a*) *Weldon freestone quarries, Northamptonshire, showing tools, and* (*b*) *Weldon quarries, showing blocks of freestone sawn to shape. The quarry adjoins the new steelworkers' town of Corby. It provided stones like these for King's College Chapel, Cambridge, from* 1508 *to* 1515, *and for Clare, Corpus, and Trinity Colleges.*

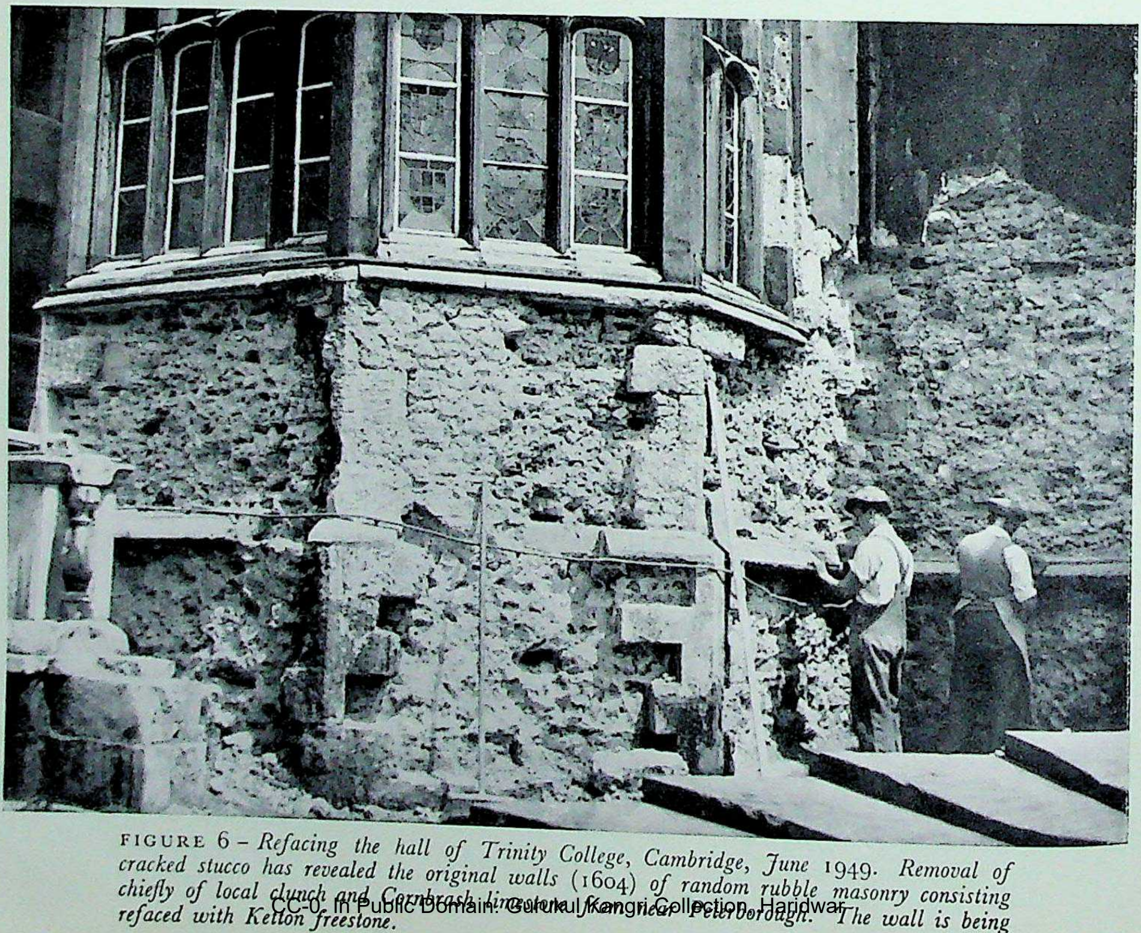

FIGURE 6 – *Refacing the hall of Trinity College, Cambridge, June* 1949. *Removal of cracked stucco has revealed the original walls* (1604) *of random rubble masonry consisting chiefly of local clunch and Cornbrash limestone from near Peterborough. The wall is being refaced with Ketton freestone.*

of a stone: colour, texture, hardness, and—most subtle but most important—durability. In the light of this it is folly to fill up old stone quarries indiscriminately with rubbish, as has been done by so many authorities all over Britain. A priceless asset has been repeatedly sacrificed in this way to the expediency of the local authority responsible for rubbish disposal. The loss of the quarry and its future potentialities is permanent; the relief of the authority is temporary, for some better method of refuse-disposal will necessarily have to be evolved and standardized in a few years, when all the quarries are full.[1]

Another danger, with a profound bearing on the aesthetic results which are admittedly one of the prime objects of building in stone, is the promiscuous use of stones from different areas solely on account of their proved durability. This danger is especially great now that costs of transport have become such a small proportion of the whole cost of building. Proximity to source of supply has been reduced by motor transport to an almost negligible advantage. Yet it is just the local stamp of the buildings in the stone areas that is the secret of their satisfying quality. To bring ironstone or granite or Mendip limestone into the Cotswolds would be just as 'monstrous an outrage' as to use red brick. On the other hand, other Jurassic limestones from anywhere along the oolite belt, from Dorset to Lincolnshire, blend perfectly with the native Cotswold stones. Clipsham stone looks quite at home in Oxford. Distance has nothing to do with it. In this way, therefore, bad mistakes can be made without any pecuniary advantage, and it is essential that geological knowledge, combined with a modicum of aesthetic sensibility, should be drawn upon by local authorities, both for their own building schemes and for the passing of plans for private schemes.

The most obvious and essential part for science to play, however, is to provide some means of ascertaining the durability of building stones, to replace the lost art of the olden-day craftsman based on natural flair and lifelong experience. This problem has been attacked with considerable success at the Building Research Station at Watford, near London. It is one of those problems that appear elementary but prove to be far from simple. Each kind of stone presents different combinations of characters, which may cause different kinds of failure in response to several varieties of weathering—sometimes predominantly chemical, sometimes predominantly mechanical, but usually a combination of the two. There is no golden rule for all stones. Each kind has to be studied individually.

For Portland stone and some similar oolites the most reliable is the crystallization test. Specimens of standard size are soaked in a 14 per cent. solution of sodium sulphate, and dried in an oven under strict control. The force of crystallization disrupts the weaker stones but not the stronger. Similar effects are produced when rain freezes in the surface layers of some stones. It might be thought that the degree of simple porosity would therefore be a good measure of durability, but this is not so. For instance, Ketton stone, an almost perfect oolite, is one of the most durable of the oolitic stones but at the same time the most porous. When a can of water is poured on a large quarry-dressed block it all soaks in; none runs off.

The reason seems to be that there are two kinds of porosity: macroporosity, due to spaces between the grains of the oolite, and microporosity, due to minute cavities within the grains. Degree of macroporosity seems to have little connection with durability, but microporosity is all-important. By delicate measurements (with a modified capillary method) it has been proved at the Building Research Station that stones of proved durability have the lowest microporosity, and *vice versa*, and the results are consistent with those obtained by the crystallization test. In future, therefore, by taking samples at suitable intervals during building operations, it should be possible to detect subtle changes in a freestone as quarrying proceeds, and to eliminate unsound material. It is essential that responsible authorities should realize that these possibilities exist, and that facilities for carrying out the tests should be available on an adequate scale when stone building becomes more general again.

When stone building is mentioned too many people think only of ashlar. In reality, ashlar masonry, requiring high-class freestone, is only the show-flower of masonry and is never likely to become general. By far the greater part of the stone buildings in Britain—cottages, farms, dwelling-houses, and barns—are built of coursed or random rubble masonry, made from walling-stone dug from small local quarries. These stones are much more generally distributed than freestone, are infinitely more easily quarried and worked, and are not subject to scaling and decay. They are, moreover, the only kind of stone suitable for the majority of buildings required outside the large towns. It is therefore in the walling-stones and coursed rubble masonry that the future of English stone building lies.

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[1] Thanks to representations through the International Geological Congress in 1948, some quarries have been saved, and at least no authority can now plead ignorance or unawareness of what it is doing. Nevertheless, constant vigilance by the public is necessary.

In the west, from Cornwall to Northumberland and in Wales, there is no freestone, yet these districts are all eminently stone ones. The local walling-stone was dug from scores of small quarries wherever a hard rock was available. The same applies also to the Cotswolds and the rest of the main oolite belt, and to the many minor stone districts for which the scenery of England is so justly famed: for instance, the ironstone towns and villages of North Oxfordshire and parts of Northamptonshire; the carstone villages and churches along the Lower Greensand outcrop in Bedfordshire, Cambridgeshire, and Norfolk; the famous grey stone villages of Purbeck, with old Swanage; the coral rag rubblestone villages of North Wiltshire and White Horse Vale, strung out from Calne by Wootton Bassett, Highworth, and Faringdon to Wytham, Old Headington, and Wheatley. These are the core and the real substance of the heritage of rural England, for the continuance of which as a living and developing organism, not a dwindling museum exhibit, the most strenuous efforts should be made.

During the last thirty years, in some districts of which the writer has personal knowledge, the local authorities have been condemning old rubble-walled and stone-slated or thatched cottages to demolition, even when architects have declared that they could be reconditioned and altered to make sound and healthy homes. The small quarries from which the indestructible and beautiful local stones are supplied, having first become disused by reason of the competition of mass-produced bricks and concrete blocks, have been systematically filled up with refuse by the local authorities. Speculative builders after the first war, and local councils after the second, have, with some notable exceptions (figure 3), planted down among the infinitely varied and infinitely vulnerable tissues of the English countryside batches or ribbons of new houses of the most barbarous incongruity and soulless uniformity in layout and materials.

To an outside observer it must seem incomprehensible that, while facilities for education are expanding at an unprecedented rate, this same population is condemning itself and its descendants to spend their lives among dreary, monotonous bricks and concrete, which at the present rate will soon sprawl from one end of Britain to the other.

It is still not too late to save much that is precious, and to redirect our building activities along less negative lines, not subordinated so entirely to temporary expediency. The stone industry is not dead and can be revived. The skill and pride of the masons and the experience and lore of the quarrymen, inherited from countless generations, are dying out but can be saved and carried on. A few miles from the worked-out Barnack quarries, whence the Romans took their milestones and coffins and the Saxons and Normans carried off the great stones for innumerable churches (figure 2), the quarrymen at Weldon still work the beautiful cream-coloured freestone (figure 5). In the adjoining parish of Corby a new town for 40,000 steelworkers is planned. What proportion of these state-aided houses will be built of the local stone that lies so abundantly to hand? Here is an opportunity for a Government-sponsored training centre for masons and quarrymen, who may learn as they work. Or will the opening up of this new town in rural Northamptonshire coincide with the final closing down of the quarries?

So far the signs are that it will. Even the new Council Houses at Clipsham, to house the quarrymen who work the Clipsham quarries, are to be of brick because the Ministry of Health will not sanction the expenditure of more than an extra £133 per house. And unfortunately, although the owner of Clipsham quarries offered the walling-stone free of charge, the additional cost works out at £300 per house.[1] This is due mainly to the extra labour for chopping or rough-dressing the stone, but also to the need for a certain amount of freestone for dressings, and to the necessity for stronger foundations and thicker walls. So for the want of £167 per house, Clipsham village is to have twelve brick homes for its quarrymen, a permanent rent in the pattern and tradition of yet another lovely village on the stone belt.

Such facts as these present a challenge which should be met officially by vigorous research into methods of reducing costs of building in stone. For instance, compressed air has revolutionised quarry-dressing of the freestone at Clipsham quarries; some mechanical means of rough-dressing the walling-stone might also be devised. If the words of the Minister of Health were anything more than mere words, these urgent matters will not much longer be allowed to go by default.

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[1] *Manchester Guardian*, 8th October, 1949.

Astronomy in South Africa

DAVID S. EVANS

South Africa has been called the astronomer's paradise, and it certainly has more active observatories for its population than any other region of the world. Circumstances have made it the centre of southern-hemisphere astronomy, and there is good hope for the eventual development of a distinctive South African school of astronomy, the achievements of which may parallel those of the older northern workers. Much has indeed already been done.

The association of astronomy with South Africa is not by any means a recent phenomenon. Centuries ago, the then newly discovered route to India began to make of the Cape of Good Hope a 'refreshment station' for ships and a fixed point in the sketchy processes of early navigation. In 1685 Jesuit missionaries under Father Tachard came to the Cape on their way to Siam, and attempted, as their successors were to do for long afterwards, to fix its longitude. The most notable of the early astronomers in Africa was, however, the Abbé La Caille, who arrived in 1751 and who, in little more than a year, accomplished a remarkable quantity of observational work, including laying the basis for a catalogue of 10,000 southern stars and making observations towards the determination of the solar and lunar parallaxes.[1] In this he foreshadowed much later work, and in addition he initiated a line of research later to be developed out of all recognition, by surveying a short length of the arc of a meridian of the earth's surface.

In those days the Cape was in Dutch hands, but in 1814, by cession and purchase, it was acquired by Britain. In 1820 the Admiralty decided that it would be advantageous to establish a permanent observatory at the Cape for the assistance of navigation, the provision of a time service for ships, and the observation of southern stars not visible from Europe. As a result the Reverend Fearon Fallows became the first of a distinguished line of H.M. Astronomers at the Cape. There he set up his observatory—the buildings of which were completed five years later—on a site to the north-east of Table Mountain from which signals to shipping in Table Bay could readily be sent. The early years were hard: the surrounding country was composed of sand and mud, and stories are extant of hippopotami in a near-by river and of a Cape tiger (leopard) found asleep on the roof shutters of the observatory. Fallows, however, was a worthy founder of a distinguished line.

He was succeeded in 1832 by Henderson, whose short time of one year at the Cape before he resigned for reasons of health was memorable for the observations which provided the first determination of the distance of a star, *Alpha Centauri*. Thomas Maclear, who followed Henderson in 1833, established the Observatory on a firm basis during his long tenure of office of 37 years. He not only made important contributions to the astronomy of the southern hemisphere, but his careful verification and extension of La Caille's arc of the meridian was of great value to geodesy. During Maclear's period of office Sir John Herschel made his well-known expedition to the Cape in the years 1834–8; he erected his father's twenty-foot reflector at Feldhausen, near Cape Town, to sweep systematically the southern skies in the same manner as his father had swept the northern. In the course of these sweeps some 1200 double stars and about 1500 nebulae were discovered; the magnitudes of the brighter stars were determined; and many special observations of interest were made.

The greatest of the successors of Fallows was undoubtedly Sir David Gill. Gill had been a pupil of Clerk Maxwell in Scotland, and after a period as an amateur astronomer had given up a flourishing business to become private astronomer to the Earl of Crawford (Lord Lindsay). It was in this capacity that he had gone to Mauritius to observe a transit of Venus, the results of which, it was hoped, would yield reliable values of the solar parallax. On the same expedition he also made observations which, by links through Aden and

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[1] The lunar and solar parallaxes are the angles subtended at the average distances of the moon and sun by a line equal in length to the radius of the earth. These angles are therefore measures of these distances, and their determination fixes the size of the solar system, providing a base line for the determination of all stellar distances.

Durban, were to fix the longitude of the Cape with considerable accuracy.

During Gill's time at the Royal Observatory at the Cape from 1879 to 1907 a prodigious amount of work was carried out. Not only did Gill continue the vast work of cataloguing the southern stars; he also accomplished a revolution in astronomy by the introduction of photography for the determination of star positions. This development originated in the photography of the comet of 1882, undertaken with the aid of a local professional photographer. It led, first, to the Cape photographic *Durchmusterung*, a catalogue in which the positions of not far short of half a million stars were determined, the reductions being carried out in collaboration with Kapteyn, the celebrated Dutch astronomer. A second consequence was the proposal for mapping the whole sky by means of photography, which later took shape as the project for the *Carte du Ciel*, in which the whole sky was to be mapped by observatories all over the world working in concert and using standard instruments. To Kapteyn's interest in this work must in some degree be attributed his discovery of star streaming—the preferential motions in space of the stars near the sun—announced by him at the British Association meeting in South Africa in 1905.

As if this were not enough, Gill also made observations for the determination of solar parallax and of the mass of the Moon, using a heliometer, in the application of which he was an adept. This instrument has a divided object glass, the relative movement of the two halves being used to secure coincidence of the images of two objects the angular separation of which is to be determined. Gill also used the heliometer for the determination of the distances of a number of southern stars, with an accuracy not surpassed until the development of photographic methods, which, requiring much less time at the telescope and much less computational work in deriving the results, have made the heliometer obsolete.

Lastly, it is to Gill that we owe the conception of the project for the survey of an arc of the meridian running right up the African continent and beyond, which would serve to determine the exact figure of the Earth. Even today this project is not complete, but it is astonishing to see the extent of the work done in Gill's lifetime, especially in view of the desolate nature of some of the country traversed—in parts of which work was impossible except when water-melons, representing the only available source of water, were ripe.

It is fitting that Gill's work should be reviewed at some length, not only because of his influence on the scientific history of southern Africa, but also because in his time the Royal Observatory developed tremendously. It was then that the 24-inch Victoria refractor, which is still in use, was acquired as a gift from Frank McClean, and it was also during his tenure of office that part of the work on the photographic charts of the southern sky was done at Cape Town by Franklin-Adams. The traditions which Gill set are still alive. The Royal Observatory is still concerned with fundamental astronomy of the southern sky—the measurement of positions and parallaxes, and more recently of star magnitudes. The determination of the solar parallax by observations of Eros in 1931, in the results of which the Cape observations played an important part, was carried out as an international project under the direction of Sir Harold Spencer Jones, now Astronomer Royal but then H.M. Astronomer at the Cape, and is in the same great tradition. The present H.M. Astronomer, Dr J. Jackson, had the difficult task of piloting the observatory through the war years, but even in face of depleted staff and other difficulties the work was continued and, especially in the field of stellar photometry, extended.

During his tenure of office Gill received a request for employment from a Mr R. T. A. Innes, an Australian amateur astronomer, who gave up business as a merchant in Sydney to come to the Cape, at first in the relatively humble capacity of secretary and librarian. However, Innes proved to be an outstanding observer of double stars, and is now remembered as the author of a standard work on this subject. In 1903 the administration which was set up in the Transvaal after the Boer war established a meteorological observatory in Johannesburg, and Innes was appointed director. At first this institution had no more than a 9-inch telescope, but later, after the formation of the Union of South Africa in 1910, it became the Union Observatory, acquiring, after the first world war, a large refractor of 26½-inch aperture. The Observatory is known particularly for its work on double stars, minor planets, and comets, and it was here that the Franklin-Adams cameras were set up, under the direction of Innes' successor, H. E. Wood, to complete the task of photographing the southern sky. The present Union Astronomer, Dr van den Bos, is also famous as a double star observer, and the Observatory has continued to specialize in the types of work already

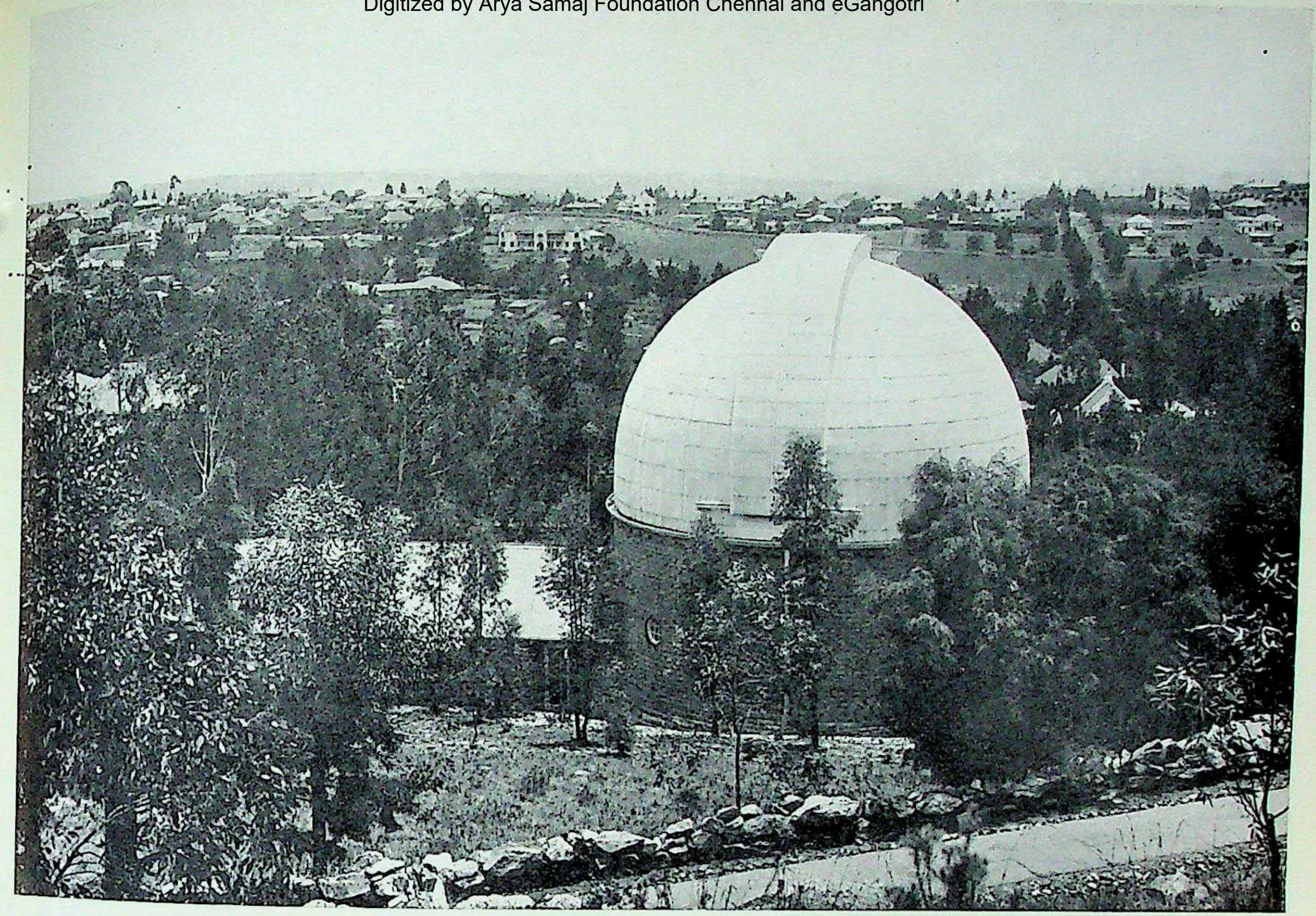

FIGURE 1 – *Dome of the 26-inch telescope at the Union Observatory, Johannesburg. (By courtesy of the Union Astronomer.)*

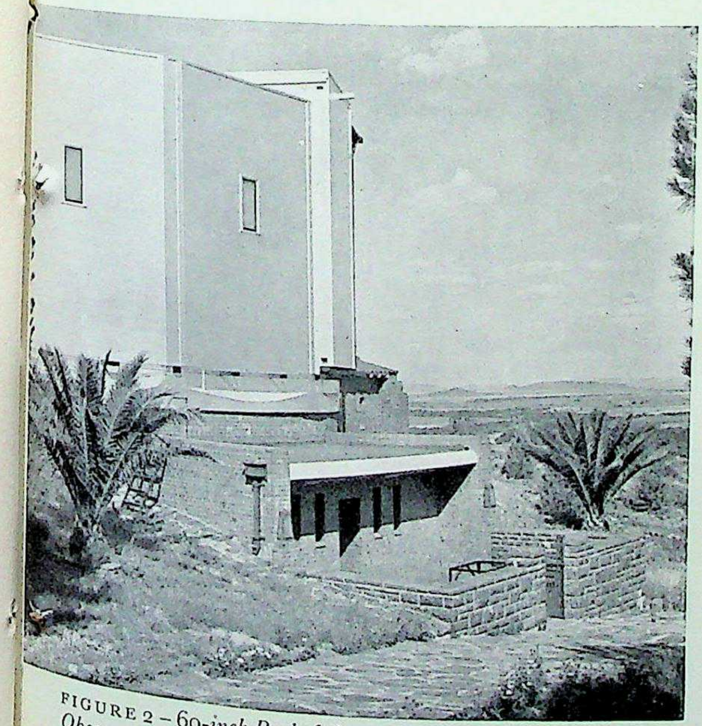

FIGURE 2 – *60-inch Rockefeller reflector turret at the Harvard Observatory, Bloemfontein. (By courtesy of Dr J. S. Paraskevopoulos.)*

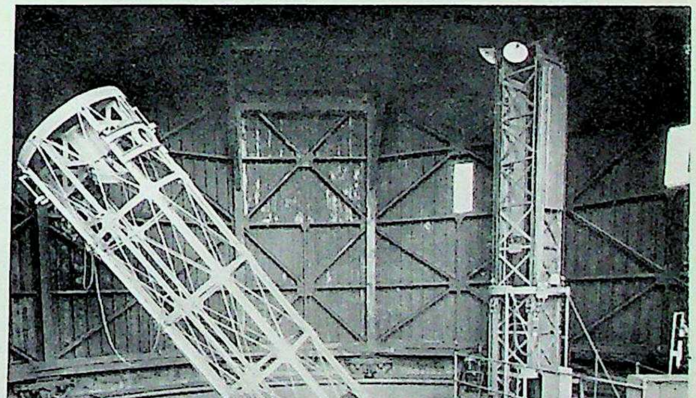

FIGURE 3 – *60-inch Rockefeller reflector at the Harvard Observatory, Bloemfontein. (By courtesy of Dr J. S. Paraskevopoulos.)*

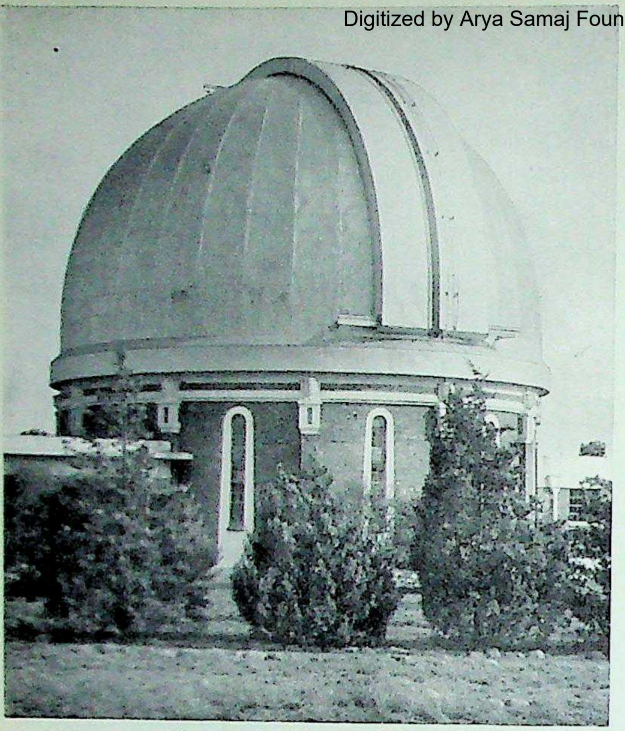

FIGURE 4 – *Dome of the Lamont-Hussey Observatory, Bloemfontein, housing 27-inch refractor.*

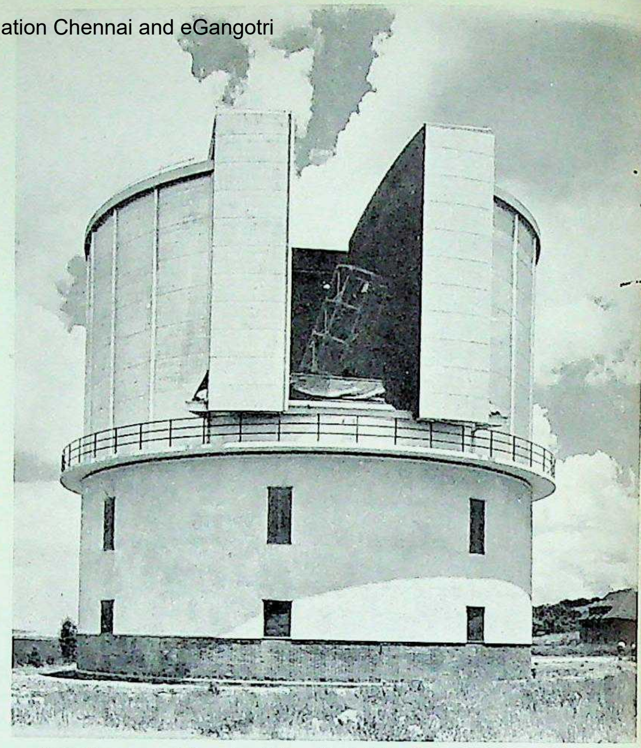

FIGURE 5 – *Turret of the Radcliffe Observatory, Pretoria. (By courtesy of the Director.)*

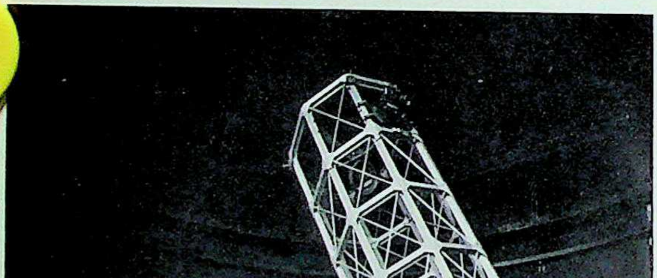

FIGURE 6 – *The Radcliffe reflector. (By courtesy of the Director.)*

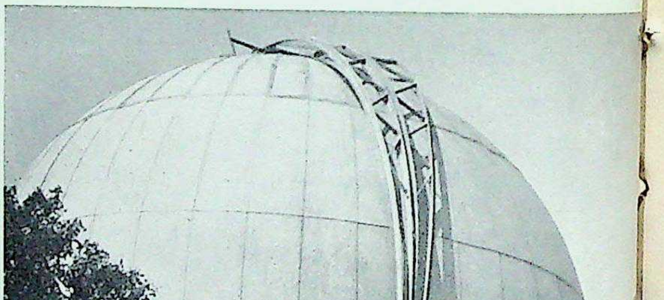

FIGURE 7 – *Dome of the Victoria telescope, the Royal Observatory, Cape Town.*

mentioned, as well as providing a time service and interesting itself in seismological work.

The Cape Observatory was originally established 'for the improvement of practical astronomy and navigation'; the Union Observatory was established to provide scientific services and a centre of research for a new state and a rapidly developing industrial area, and has grown with them. But the interior of southern Africa, of which the country round Johannesburg is fairly typical, has quite extraordinary advantages from the astronomical point of view. Its altitude of more than 5000 ft makes an appreciable difference to the absorption of starlight by the atmosphere. The climate is ideal: during half the year the sky is almost completely cloudless, and even during the southern summer, from October to March, when rain does fall, it does so in brief, violent thunderstorms which leave the air washed clean of dust and of an astounding transparency and steadiness. Moreover, all these advantages are to be had in a region from which the relatively very badly explored southern sky is visible.

All these factors have combined to attract astronomers to southern Africa. In 1925 the southern station of the Yale University Observatory was set up by Professor Schlesinger under the direction of Dr Alden in the grounds of the University of the Witwatersrand in Johannesburg. The equipment includes a 26-inch photographic refractor used for the observation of parallaxes and proper motions of southern stars, and this work has been continued under the direction of Professor C. Jackson, now director of the Yale-Columbia station, who as a former member of Innes' staff can in a way be regarded as a scientific grandson of Gill. In 1926 a temporary solar station was set up by the Smithsonian Institution on Mount Bukkaros in South-West Africa, and in the same year the Lamont-Hussey Observatory of the University of Michigan, equipped with a 27-inch visual refractor, was established at Bloemfontein. This city, the capital of the Orange Free State, is some 300 miles south of Johannesburg and at a lower altitude, but the climate and topography are very similar. The refractor, in the hands of Dr Rossiter, has been the means of discovery of many thousands of new double stars.

In the next year the Boyden station of Harvard College Observatory was established at Maaselspoort, a few miles outside Bloemfontein. In 1887 Uriah A. Boyden of Boston had bequeathed a large sum to Harvard for astronomical observations at high altitude, and the bequest was first used for work at Arequipa, Peru. However, the summers there proved almost uniformly cloudy, and in 1927 Dr J. S. Paraskevopoulos brought the station to Bloemfontein. The equipment is elaborate, and includes a reflector of 60-inch diameter, the Bruce 24-inch photographic refractor, and a photovisual refractor of 13-inch aperture. The last instrument has been used with an objective prism for spectroscopic work, while small cameras, of which there are several, are used for regular patrol surveys of the sky. The main function of this station is to supply southern sky material to Harvard Observatory, and, on this, extensive researches on photometry, star distribution, and variable stars have been based.

Over many years, by interchange of visits and in other ways, close relations had been maintained between the Union Observatory in Johannesburg and observatories in Holland, particularly that of Leiden University. Just before the second world war this collaboration was carried a step further when Leiden, aided by a Rockefeller grant, established in the grounds of the Union Observatory a large double refractor of 16-inch aperture. This instrument has been used for photometric work of various types, and recently an electron multiplier apparatus for direct photometry of stars has been installed. The present observer is Dr Wesselink, successor to the late Dr van Gent, who throughout the war had continued work with this telescope.

From November 1931 to March 1933 Leiden had also maintained a station on the equator, in Kenya, at a very high altitude for the purpose of making fundamental determinations of stellar declinations, and a similar station was re-established in 1947. Quite apart from this, which perhaps hardly falls within the ambit of a sketch of astronomy in southern Africa, we have enumerated no fewer than six permanent astronomical stations in the Union of South Africa itself, those at Cape Town, the Michigan and Harvard stations at Bloemfontein, and the Union Observatory, Leiden station, and Yale-Columbia station, all in Johannesburg. In addition mention must be made of a station terminated by the war, established by Breslau University at Windhoek in South-West Africa at an altitude of over 5000 ft, in a climate where the maximum humidity is 40 per cent. and the sky almost completely cloudless at all times. The Union itself is also the scene of considerable amateur astronomical activity, including the private observatory maintained for many years at Lovedale in the Eastern Cape by the late Dr Roberts, where important pioneer observations of southern variable stars were made.

With the exception of the Union Observatory, all the permanent institutions so far mentioned have represented offshoots or southern stations of previously existing northern-hemisphere organizations. The Radcliffe Observatory at Pretoria, directed by Dr H. Knox Shaw, is the only one which has been transferred from Europe to a better climate and an ampler sphere of activity. Founded in Oxford in the latter part of the eighteenth century out of endowments left by John Radcliffe, principal physician to Queen Anne, the observatory was transferred in 1937 to Pretoria, where the Radcliffe trustees agreed to provide a reflecting telescope of 74-inch clear aperture, the largest in the southern hemisphere. Ill luck dogged the casting of the disk for the main mirror, and work was considerably delayed by the war. Only in 1948 was the completed disk delivered and installed. The telescope, which has a moving weight of 45 tons, is installed in a turret structure on the summit of a ridge overlooking Pretoria. So far it has been used only at the Newtonian focus, and not until very recently has a spectroscope become available. Much of the time of the small staff has been occupied in installation and modification and in bringing new apparatus into use, but even so a considerable amount of work has already been done in direct photography of nebulae, and in the beginnings of surveys of particular classes of interesting objects. An important programme which will be started when the Cassegrain spectrograph becomes available will be the determination of radial velocities of the bright B-type stars (hot blue stars showing a hydrogen spectrum, whose great intrinsic brilliance makes them visible even at a very great distance). The object of this work will be to supplement similar investigations made on northern-hemisphere stars, and its results will enable fundamental data on the rotation of the Milky Way to be derived. It is clear, however, that in addition to this there is an almost unlimited field of galactic and extragalactic objects still to be investigated.

Book reviews

ORGANIC CHEMISTRY FOR EVERYMAN

A Direct Entry to Organic Chemistry, *by John Read. Pp. xiii + 268. Methuen and Company Limited, London.* 1948. 4*s*. 6*d*. *net.*

Professor Read's exceptional talent for explaining intricate chemical subjects to the lay public has probably never been seen to so great advantage as in the present little book. Organic chemistry, of course, is in its main features much more readily comprehensible to the non-scientist than, say, physics or inorganic chemistry, the basic conceptions of its theory being often similar to those of ordinary daily life. For example, the idea of isomerism presents no difficulty to a builder who constructs many different houses out of the same quantities of bricks and tiles. Nevertheless, to lead the novice so far along the path of organic chemistry as to render intelligible to him the mysteries of rubber, penicillin, haematin, Perspex, nylon, fats, camphor, chlorophyll, vitamins, etc., requires not only a mastery of the subject itself but a great facility in exposition—and a shrewd appreciation of human nature. It can occasion no surprise that Professor Read's book has been awarded the Europeo Cortina prize of one million lire for the best popular scientific work published in any language during the past four years. The honour was well deserved and will be generally acclaimed. The book itself is not entirely free from misprints, and the reviewer was surprised that such a polished stylist as Professor Read should use the word 'phenomenal' as equivalent to 'vast.'

FATTY ACIDS

Fatty Acids and Their Derivatives, *by A. W. Ralston. Pp.* 986. *Chapman and Hall Limited, London; J. Wiley and Sons Incorporated, New York.* 1948. 60*s*. *net.*

There are now a number of books dealing with natural fats—their general occurrence and constitution, their importance in biochemistry and nutrition, and the applications and processing of fats in general (or specific groups or even individual fats) for the various industrial products into which they enter. The present work differs from any of these in that it sets out to give a comprehensive account of all the fatty acids, natural or synthetic, which contain a chain of six or more carbon atoms. At first sight this may seem supererogatory, but the assemblage of data in this field has required a volume of nearly 1000 pages and reference to over 5000 original papers and patents, which are fully annotated. This may serve to indicate that the treatment of the fatty acids as a subject in themselves was worth undertaking, and in Dr Ralston's hands it has been very effectively carried out. It is, of course, largely a book for the specialist. The research worker in this field will find it most useful since it is an almost complete collection of all data, physical and chemical, connected with the fatty acids themselves, their esters, and many of their other derivatives. Chemists concerned in the development of all the fat and soap industries will also find the book of the greatest value. This is not to say that the volume is without interest to the general reader or student; on the contrary, its perusal will convey to them not only the chemistry of the fatty acids, but will give a coherent picture of the different classes of natural fats and of their transformation into soaps, their hydrogenation to products of specific suitability for different uses, and so on, since all these aspects are touched upon in some detail incidentally to the main objects of the book. The primary objective, however, has clearly been to assemble a complete account, physical and chemical, of the fatty acids and their derivatives, and thus it will find its greatest use among those actively engaged in the study, academic or technical, of fatty products.

T. P. HILDITCH

CHEMISTRY OF COAL

Elements of Coal Chemistry, *by D. J. W. Kreulen. Pp.* 204, *with half-tone and line illustrations. Nijgh and Van Ditmar N.V., Rotterdam.* 1949. *fl*18.25.

In 1935 Dr Kreulen published *Grundzüge der Chemie und Systematik der Kohlen* which was designed to enable students to consult specialized literature on the chemistry of coal and also to present the author's views on various aspects of that subject. The present book is an entirely re-written second edition, and contains 17 chapters ranging from coal classification to the hydrogenation of coal.

The important work of Odén on humic acids is described in detail, while the physico-chemical work on the humic acid curves will repay careful study. Coal bitumens and the micellar structure of coal also receive good treatment within the limits of the space available.

In general the translation has been well done, although there are a few strange words and phrases—which, however, are not confusing. The book contains 51 tables and 70 figures, and the printing and binding are very good. There is no index, but at the end of each chapter numerous literature references are given; these would have been more useful if they had been numbered and indicated in the text. The author has produced an up-to-date and concise survey which should be very helpful to all interested in the subject.

ARTHUR MARSDEN

PLANT PHYSIOLOGY IN HOLLAND

Fifty Years of Plant Physiology, *by Th. Weevers. Pp. xi* + 308. *Scheltema and Holkemas Boekhandel en Uitgevers Maatschappij, N.V. Amsterdam.* 1949. *n.p.*

There is a splendid tradition of plant physiology in Holland, and in recent years Dutch botanists have opened up several new fields of research. Not many English-speaking botanists can read the Dutch language easily, and it is therefore a pleasure to receive from a senior Dutch botanist a summary of plant physiology in Holland over the last fifty years.

For that is what the book is. Notwithstanding its title, it makes no pretence to be history or to cover the whole province of plant physiology. Professor Weevers just talks charmingly about the work of Dutch physiologists and some others. He ably summarizes the state of knowledge up to 1895, and sketches, with the familiarity of a lifetime, the advances made since then, particularly by his own countrymen. And an impressive story it is. Much of the work is already familiar to British plant physiologists, but by no means all. Professor Weevers has so much inside knowledge that facts one knew only from research papers are suddenly illuminated by some comment of his in this book.

In an introduction, Professor F. W. Went suggests that the literal translation lends colour to the book (which it certainly does) and makes it possible to follow more closely the author's meaning (which is unfortunately not true). It is a pity that, in the translation, so much of Professor Weevers' individuality is obscured by a quaint and ambiguous phraseology.

E. ASHBY

VACUUM TECHNIQUE

Scientific Foundations of Vacuum Technique, *by Saul Dushman. Pp.* 882, *with numerous line drawings. John Wiley and Sons Incorporated, New York; Chapman and Hall Limited, London.* 1949. 90*s. net.*

This comprehensive book gives a survey of those fundamental ideas of physics, chemistry, and metallurgy which will be found to be of use to scientists and engineers who are faced with problems which arise in the production, maintenance, and measurement of high vacua. It includes chapters on the kinetic theory of gases and fluid flow; pumps of all varieties; the measurement of low pressures; the interaction of gases with solids, including metals; dissociation and vapour pressures; and rates of evaporation. The wealth of information contained in this book is based on the author's long and distinguished experience in the laboratories of the General Electric Company.

The field of vacuum technique is only as old as the incandescent lamp, yet today it finds applications as diverse as in the smallest receiving valve to a 100 kW transmitter; the synchrotron, betatron, and other high-voltage equipments used in nuclear physics; X-ray tubes of up to two million volts; and liquefiers and other equipment used in low-temperature physics. This treatise should prove to be an invaluable source book and reference book to all who design high-vacuum equipment or use high-vacuum techniques, and all workers in these diverse fields are under an immense debt of gratitude to Dr Dushman for undertaking the task of writing it.

A. R. MILLER

TEXTBOOK OF ZOOLOGY

Traité de Zoologie. Anatomie, Systématique, Biologie, *publié sous la direction de M. Pierre-P. Grassé.* Tome XI: Echinodermes, Stomocordés, Procordés, *par L. Cuénot, C. Dawydoff, P. Brien, C. Drach, etc. Pp.* 1075, *with over* 450 *line diagrams. Masson et Cie., Paris.* 1948. 3800 *francs.*

Volume XI is the first of the 17-volume *Traité* to appear. It covers fossil and living echinoderms, hemichordates and graptolites, tunicates, and cephalochordates. This is a wide field, but although the difficulty of achieving an up-to-date account of each aspect has been overcome by composite authorship, the book remains coherent in plan, and consistent and lively in treatment. Most of the illustrations are excellent, and either original or carefully brought up-to-date, but colours and stereograms seem insufficiently used. The book is clearly printed on good paper.

The morphology and physiology are lucidly expounded, with good summaries; in many cases, e.g. *Amphioxus* nervous system, long-established facts reach a text-book for the first time. Perhaps recent work is overstressed and function deduced from structure not always distinguished from that experimentally demonstrated. Gaps in our knowledge are explicitly stated. The developmental and systematic accounts are excellent, and the inductive reasoning on which different phylogenetic theories are based is clearly visualized. The hemichordates are held, probably correctly, to be closer to the echinoderms and further from the chordates than has been recently assumed.

A revision of these groups has long been needed and this very usable book should be a standard work for many years.

H. P. WHITING

CYBERNETICS

Cybernetics: or Control and Communication in the Animal and the Machine, *by Norbert Wiener. Pp.* 194. *Chapman and Hall Limited, London.* 1949. 18*s. net.*

Cybernetics is a new word, evidently derived from the Greek, meaning to steer. The author of the book under review is Dr Norbert Wiener, a distinguished American mathematician who is a professor at the Massachusetts Institute of Technology, and the subject is automatic controls.

The theory may be said to have begun with Clerk Maxwell's paper of 1868 *On Governors*, in which he discussed mathematically the operation of such contrivances as Watt's governor for steam engines. Now we have innumerable mechanico-electrical systems which are designed to perform quasi-human functions — automatic gyro-compass ship-steering devices, self-propelled missiles which seek their target, and machines for solving elaborate mathematical problems. Many possess sense organs such as photocells or thermometers, and the equivalent of a central nervous system to integrate the transfer of information from their perceptive to their executive elements. Some have even a memory. They lend themselves to description in physiological terms.

The industrial revolution of the last century devalued human strength in comparison with machinery: the pick-and-shovel labourer could not compete with the steam excavator. Will there be a new industrial revolution in which another large group will be thrown out of work by the competition of cybernetic mechanisms? E. T. WHITTAKER

METALLIC ELASTICITY

Elasticity and Anelasticity of Metals, *by C. M. Zener. Pp. x* + 170, *with half-tone and line illustrations. University of Chicago Press, Chicago; University Press, Cambridge.* 1948. 22*s.* 6*d. net.*

It is customary in the classical treatment of elasticity to divide the subject into two main sections, the elastic or pre-plastic, in which Hooke's Law is followed, and the non-elastic, which is characterized by the existence of a permanent set. It has, however, been recognized for more than a century that there are departures from Hooke's Law at quite low stress levels, although these deviations were regarded as happy hunting-grounds for the theorist and as not having any particular value for the practising metallurgist. Within the last ten years or so such deviations have assumed great practical value, and the study of them has led to marked advances in our knowledge of the microstructure of solids.

The term 'non-elastic' has attached to itself the connotation of permanent set, and it has been recognized that a new term is necessary to avoid misconceptions. The term 'anelasticity' is therefore formally defined as 'the property of a solid in virtue of which stress and strain are not uniquely related in the pre-plastic range.'

This volume—the first of a series of monographs to be issued by the newly formed Institute of Metals—is an interesting and important contribution to the study of the microstructure of metals, and it can be strongly recommended as a lucid summary of an important branch of the subject of elasticity.

ALLAN FERGUSON

ORGANIC IDENTIFICATION

The Systematic Identification of Organic Compounds, *by Ralph L. Shriner and Reynold C. Fuson. Third Edition. Pp.* 370. *John Wiley and Sons, New York. Chapman and Hall Limited, London.* 1948. 13*s.* 6*d. net*

This work is a stimulating guide to students of chemistry in that section of their university training which, to quote from the authors' preface, 'is the best experience for those preparing for research' whereby they 'are introduced to the methods which it involves.' 'The large amount of research which has been done recently . . . in connection with the preparation of derivatives suitable for characterization' is obvious from chapters VI and VII. References to the literature are numerous, and mostly from the years since 1939. Much emphasis is laid on the mechanism of reaction. Under Schiff's aldehyde test the constitution of the reagent itself and of the compound which results is made clear; modern work on the structure of bisulphite compounds is cited and the student is invited to inquire why cinnamaldehyde combines with two molecules of sodium bisulphite. Mercuration is introduced through a reagent for unsaturated compounds and for aldehydes and ketones, although this subject in general is not surveyed.

Sulphonic acids receive excellent treatment, but the interesting derivatives of the 'chloramine-T' type are omitted, probably because their chief use lies in the formation of sulphilimines from the lesser-known arsines and sulphides. Mercaptans, however, receive consideration.

The mention of the oxonium compounds formed from ketones and esters, and the discussion of the hydrogen bond in relation to physical properties, again reveal a modern outlook.

Practical organic chemistry was never mere 'cookery.' This book reveals it as a fine and inspired art.

FREDERICK CHALLENGER

SEA SHORE BIOLOGY

The Sea Shore, *by C. M. Yonge, F.R.S. Pp. xvi* + 311, *with numerous coloured plates, half tones, and line drawings. Collins' New Naturalist series, London.* 1949. 21*s. net.*

This is an extremely welcome and attractive book. It is addressed to the general public and is pleasantly and clearly written so as to be readily comprehensible to any reader. It is also of a standard which makes it most valuable to students of biology, and to teachers of the subject whose specialization lies along other lines. It is up-to-date, and has the great advantage of having been written by an author who is thoroughly familiar, at first hand, with the wide field he has covered, and who has had long experience of seashores, not only in Britain but also in other very distant parts of the world. This means that while it deals with the British area, the author's range has been wide enough to enable him to write it against a background of world experience. Thus it contains much of general biological interest. There have been a good many books on the British shores, but this is the best and the most widely informed. The author is much to be congratulated. Another important feature is that the book is illustrated by numerous coloured and monochrome photographs by that outstanding recorder of marine subjects, Dr D. P. Wilson of Plymouth. Many of the plates are excellent, though they are variable in quality, mainly because colour-photography has not advanced quite to the point where an entirely consistent level of success can be expected with close-ups of this type. The best give a most vivid idea of the organisms portrayed, and one (the *Octopus* on plate 17) is magnificent because it combines decorative success with biological appeal.

T. A. STEPHENSON

ENDEAVOUR

A quarterly review designed to record the progress
of the sciences in the service of mankind

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The accessibility of knowledge

The first task of a scientist entering a field of research is to master the facts already discovered by earlier workers and then to keep abreast of the discoveries of his contemporaries pursuing the same line. In theory, this process is very simple; in practice, the barriers between the research worker and the facts he needs are often so formidable as seriously to impede the progress of science. In many fields, the accumulation of earlier work and the output of new publications are so great that research in the laboratory is outweighed by that in the library. Even the most conscientious reader frequently finds that he has missed papers which would have filled essential gaps in his knowledge, and awareness of which would have saved weeks or months of laboratory work. The boundaries of the main subdivisions of science either have become blurred or have disappeared altogether, and, as a consequence, there has come into existence a flood of highly specialized new journals. Among so many, it is easy to overlook specific contributions, even those of significance. Consider, for instance, the comparatively new but already important field of antibiotics. Articles on this subject, or articles in some way relevant, may be found not only in journals primarily devoted to it but in other publications, such as those dealing with general science, clinical medicine, surgery, pathology, biochemistry, chemistry, agricultural science, phytopathology, pharmacology, chemical engineering, mycology, bacteriology, nutrition, chemical analysis, and statistics.

There is the further problem of insuring that every research worker knows of developments in branches of science other than his own. In this age of specialization the importance of such access is too often under-estimated, despite the countless examples of problems in one field of science being solved by the application of methods developed in another. For example, polythene, discovered during investigations of chemical reactions at very high pressures, became a decisive factor in the development of radar, and dyestuffs developed by organic chemists have proved of inestimable value to biologists in differentiating tissues and other structures under the microscope, and as sterilizing agents or disinfectants. The task of reporting progress in all branches of science in a form intelligible to scientists as a whole falls upon the scientific reviews.

The fact that science is in danger of suffering from its own weight is apparent to many, but it is not yet so widely recognized as its seriousness demands, although in recent years it has been the subject of very wide discussion. To state the problem is, of course, far easier than to solve it, and it is clear that so far no complete solution has been found.

Certain useful steps have, however, been taken to ease the burden on the research worker. Most notable is the publication of journals of abstracts, the helpfulness of which is too obvious to need emphasis; yet journals of abstracts have inherent disadvantages which make it impossible for them to give the ordinary research worker a complete guide to existing knowledge in his own particular field. The brevity of abstracts inevitably means that they often omit all mention of information contained in the paper except that which is immediately relevant to the main issue. Moreover, abstracts must necessarily appear some time after the original publication, and therefore still longer after the original work was done. Even the most diligent use of abstracts will, as a rule, give no information about work done less than a year previously. Furthermore, in classifying abstracts, it is for administrative reasons necessary to follow the main stream of scientific progress, whereas many individual research workers today are trying to make their way across the current. Take, for example, chromatography, which has now proved of fundamental importance in almost every branch of chemistry. To follow the course of developments in chromatography itself by studying chemical abstracts is an extremely difficult task, for references to it may be found among papers relating to almost every branch of chemistry. Moreover, if the use of chromatography was merely a means to an end the abstract may not even mention that it was used.

Another way in which the burden on the research worker is being eased, and one which will certainly soon be more highly developed than it is at present, is by the growth of a class of professional literature-searchers, either free-lance or attached to science libraries, who are prepared to summarize, as far as possible, all available literature on any particular subject. Such services are most valuable for many purposes, but a disadvantage is that the professional literature-searcher can never approach his task in quite the same way as would the research worker himself.

The recent development of services for supplying microfilm and photostat copies of papers not normally available except in the largest libraries has been a further notable advance in solving the problem of making the literature of science more easily accessible to those who need it—though it does not, of course, assist the scientist in his primary task of discovering the existence of papers which will be helpful to him.

In fields in which the greatest amount of work has already been done, the accumulation of literature tends to be so great that the mechanical task of sorting it out is unduly onerous. To overcome this difficulty, some degree of mechanization has been introduced into library practice. In the commonest form, cards are punched in patterns characteristic of the information they carry, and machines—sometimes very complicated—sort out from the remainder the cards carrying any desired combination of marks. Progress has been made, too, in rendering even more concise the symbolism commonly used in most branches of science; in organic chemistry, in particular, several methods have been developed expressing structural formulae unequivocally in code form.

In spite of all that has been done to help him, the average research worker, unless he happens to be able to make full use of a well-endowed library large enough to offer some of the special services described above, is still very largely dependent on his own efforts, and on the service provided by the abstracting journals. As such special library facilities are likely to expand only slowly, no rapid alteration in the situation is to be foreseen. Accordingly, it is perhaps appropriate to suggest one way—too widely neglected—in which the scientist, especially the younger scientist, can be taught to help himself more effectively. This is by the inclusion, at an early stage in the university science course, of detailed instruction in the use of the science library. At present, far too many scientists graduate without ever having thoroughly learnt where and how they can most probably expect to find information on any particular subject. To track down information speedily and successfully requires both a wide general knowledge of the bibliography of science and a knowledge of modern library practice—in particular, knowledge of the use of card indexes prepared according to the conventional systems of classification. There are, it is true, several excellent books on this subject, but they seem to be little known and less appreciated. The burden of scientific knowledge is today too vast for anybody to carry more than a tiny fraction of it constantly in mind, and many will refuse to rely on memory when important issues are at stake. The really essential thing is to know where to find information quickly when it is needed. A former Master of Balliol College, Oxford, is said to have advised all freshmen at their first interview with him to 'verify your references and don't buy your wine in the town.' We can whole-heartedly recommend at least the first half of this admonition to all aspiring scientists. The scientist who can make the best possible use of whatever library facilities he possesses gains so great an advantage that the matter is too important to be left to chance. Every student of science should be specifically instructed in the bibliography of science.

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Nuclear reactors in scientific experiments

SIR JOHN COCKCROFT

Nuclear physics has very rapidly become one of the most important and fruitful branches of science. Even at this very early stage of development its wealth of possibilities is plainly apparent, and the control of matter which it is placing at man's disposal seems likely to be immense. Sir John Cockcroft, director of the Atomic Energy Research Establishment at Harwell, England, here discusses some of the ways in which nuclear reactors are applied.

The progress of nuclear physics has depended very much on the development of new techniques. The simple scintillation counter, together with α-particles from radium, provided for Rutherford and Marsden the tool which led to the concept of the nuclear atom. Later, in Rutherford's hands, they were used to discover the artificial disintegration of elements. The development of electronic counters for protons and α-particles, together with the Wilson chamber, made possible the discovery of the neutron. The high-voltage particle accelerator and the cyclotron, by greatly increasing the intensity of sources of protons, neutrons, and α-particles, made possible a new range of experiments, a range which is still developing.

The atomic pile or nuclear reactor in its turn has provided us with another tool of great importance, and already many new experiments are being made possible. The reason is that the nuclear reactor provides a very large number of neutrons from the fission of uranium. Inside the pile we have a source of fast neutrons, with energies of the order of 10^6 electron volts (eV), or velocities of the order of 10^9 cm/sec. The pile slows these fast neutrons to thermal velocities. Outside the pile we can therefore provide a source of slow neutrons, with energies of the order of 0·02–1000 eV, or velocities of $2{\cdot}2 \times 10^5$ cm/sec to 200 times this value. If we compare the intensities of slow-neutron beams which can be provided by the pile with those provided by the cyclotron we find that a typical research pile has a substantial advantage, an advantage which enables us to make experiments not possible on the cyclotron.

In order to understand these experiments it is necessary to know something about the characteristics of atomic piles. Figure 1 shows the principle of construction of a graphite pile.

A mass of several hundred tons of pure graphite is interspersed with a lattice of uranium metal rods. This is usually known as the reacting core. Surrounding the core is a layer of graphite known as the reflector, since it serves to reflect most of the neutrons escaping from the core back into the reacting system. Round the reflector is a shield of concrete which absorbs the greater part of the radiations escaping through the reflector, and so prevents the radiation outside the reactor from reaching an intensity harmful to health.

The intensity of the nuclear reaction inside the reactor is governed by so-called control rods, which are metal rods containing materials of high neutron absorption, such as cadmium or boron. These rods are used to control the death-rate of neutrons inside the reactor. The course of the nuclear reaction is determined by the reproduction-constant of the neutrons. A neutron produces a fission of uranium, and in so doing releases perhaps two neutrons in the splitting-up of the uranium nucleus. A number of these neutrons escape from the reactor; some of them are swallowed up in reactor materials without producing fission, but on the average a fraction K survives to produce a further fission. If K is greater than unity, the neutron population and the intensity of reaction increase. If K is less than unity, the population decreases.

When the control rods are fully inserted, K is less than unity, and the chain reaction does not develop. To start up the reaction we withdraw the control rods until K is a little over unity. We then find that the neutron population, and with it the heat developed and the general radiation intensity, increase as

$$e^{4 \times 10^4 (K-1)t}$$

where t is measured in hours. An excess K of 2·5 parts in a hundred thousand gives the pile a period of one hour. In practice we withdraw the control rods to give the reactor a period of a few minutes; we allow the pile power to increase to the desired value, and then insert the control rods to make K equal to unity. The power then stabilizes

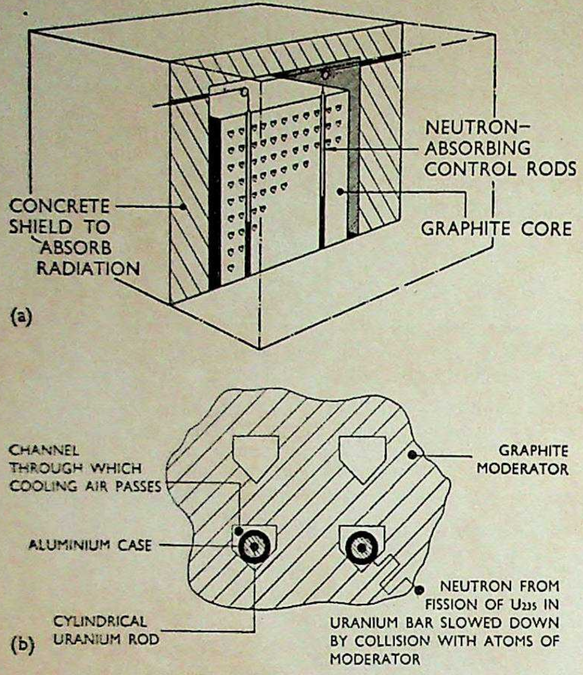
NEUTRON-ABSORBING CONTROL RODS
CONCRETE SHIELD TO ABSORB RADIATION
GRAPHITE CORE
(a)
CHANNEL THROUGH WHICH COOLING AIR PASSES
GRAPHITE MODERATOR
ALUMINIUM CASE
NEUTRON FROM FISSION OF U235 IN URANIUM BAR SLOWED DOWN BY COLLISION WITH ATOMS OF MODERATOR
CYLINDRICAL URANIUM ROD
(b)

FIGURE 1 – (a) *Section through graphite pile.* (b) *Section through graphite pile, showing method of embedding uranium rods, encased in aluminium, in the graphite moderator.*

itself and remains very constant—to within a few parts in ten thousand.

The reproduction constant is affected slightly by changes of temperature and barometric pressure: a pressure change of a few millibars is detectable. Small adjustments must therefore be made to control the rod positions, and this is usually done by a servo-mechanism actuated by a radiation intensity meter.

For experimental work we are interested in the flux of neutrons—the number crossing one square centimetre in a second at the point of the experiment. We also require to know the velocity spectrum of the neutrons. The neutron flux is directly proportional to the amount of heat developed in the reactor, and more specifically to the amount of heat developed per unit mass of the fissile isotope U235. This is because the heat developed, which comes mainly from the kinetic energy of the fission fragments, is proportional to the number of fissions, and this in turn determines the neutron flux.

Simple reactors such as the Harwell GLEEP (figure 3), which have very little cooling, can operate comfortably at a power level of 100 kilowatts. By fairly simple air cooling the second Harwell reactor develops a thermal energy equivalent to several thousand kilowatts. Water cooling of the uranium, or more intensive air cooling, allows still higher energy releases to be obtained.

The second Harwell reactor will have a maximum flux of fast and slow neutrons of the order of $2{\cdot}5 \times 10^{12}$ neutrons/cm^2/sec. The graphite research reactor being built at the Brookhaven National Laboratory in the United States will have a slow neutron flux of 5×10^{12} neutrons/cm^2/sec. [1]. Heavy-water reactors have a higher neutron flux for a given total power. This is because they use substantially less uranium metal, owing to the higher potential K of a heavy-water reactor. For a fixed power, the power per unit mass of fissile material is therefore higher, and, in general, neutron fluxes are an order of magnitude higher. The Canadian research reactor at Chalk River has been stated [2] to provide a slow neutron flux of 3×10^{13} neutrons/cm^2/sec.

The neutron flux is a maximum at the centre of the pile, and follows a cosine distribution decreasing by a factor of 5 to 10 at the edge of the reacting core:

$$\cos\frac{\pi x}{a},\quad \cos\frac{\pi y}{b},\quad \cos\frac{\pi z}{c},$$

where the approximate reacting core dimensions are $2a$, $2b$, $2c$. The flux decreases through the reflector, and falls by a factor of about 10 for each foot of concrete in the shield.

The region of high flux can be extended into the shield, and brought to its face, by piercing the shield with experimental holes which may be of 4–12 inches in diameter. These holes are filled with graphite if we wish to have a high flux of slow neutrons near the surface of the reactor. They are left empty if we wish to work with fast

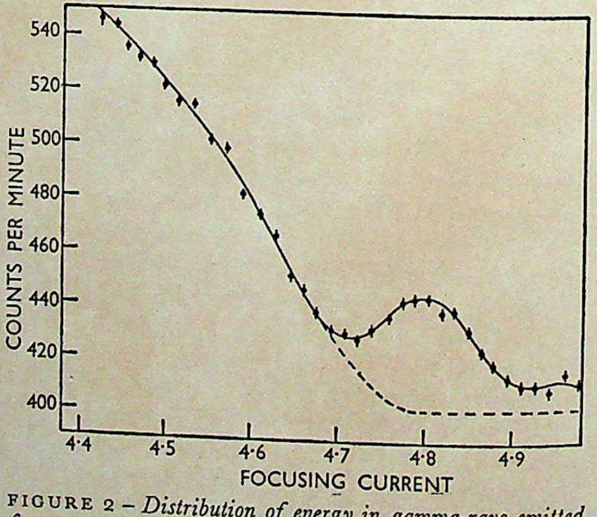

FIGURE 2 – *Distribution of energy in gamma-rays emitted from paraffin after neutron capture.* (*After Elliott.*)

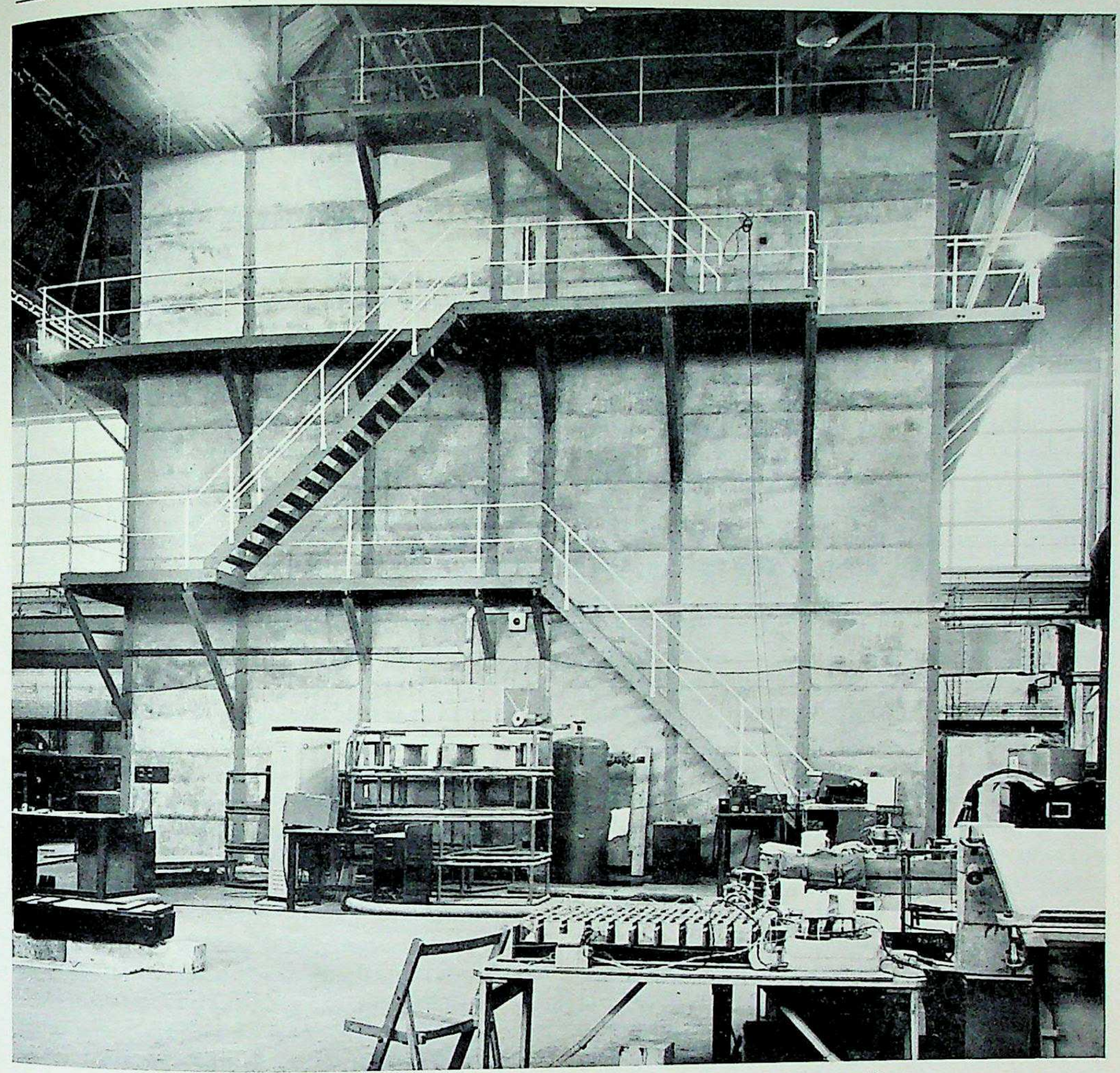

FIGURE 3 – *Face of the Harwell GLEEP.* (*Crown copyright reserved.*)

neutrons. We also provide in the shield a 'thermal column' of graphite extending from the reflector to the face of the shield. Neutrons diffuse along this graphite column, and would emerge at the face were they not stopped by a cadmium shutter which absorbs the thermal neutrons. When the thermal neutrons are stopped, gamma-rays are emitted by the capturing nuclei, so that it is necessary to fit a lead shield outside the cadmium to absorb these rays.

The thermal-neutron flux decreases as we go outward along the thermal column. When the reactor central flux is of the order of 10^{12}, the flux two feet back from the face of the thermal column will be about 6×10^8.

EXPERIMENTS WITH REACTORS

1. *Neutron beam experiments*

Beams of slow neutrons can be obtained from the pile by removing the concrete plug from one of the experimental holes and inserting graphite together with suitable collimating tubes, or by using the thermal column.

An interesting group of experiments measures the energies of the gamma-rays produced when slow neutrons are captured by different nuclei. This provides a measure of the energy with which successive neutrons are bound to the nucleus, and thus will give us some guide to nuclear structure.

The earliest example of this process to be studied was the capture of neutrons by hydrogen.

Lea [3] identified these 'capture' gamma-rays and approximately measured the cross-section for capture. Chadwick and Goldhaber [4] studied the reverse process of the photo-disintegration of the deuteron by the Th.C^{11} gamma-rays, and from measurement of the energy of the disintegration protons deduced a value for the binding energy of the deuteron of 2·1 MeV. Since that time, the photo-disintegration process has been more accurately studied by using gamma-rays from a high-voltage generator.

Recently, Elliott and Bell [5] have used the Chalk River pile to determine the energy of the captured gamma-rays very precisely. In these experiments a slab of paraffin 25 in. square by 5 in. depth was placed in the thermal column of the pile. Thermal neutrons are captured in the paraffin, producing gamma-rays. These gamma-rays are collimated by a conical shell of lead having a half-angle of 15°. The gamma-rays strike a uranium radiator and eject photo-electrons from the K and L shells of the uranium atom. The photo-electrons enter a β-spectrometer, which measures their energies and so enables the gamma-ray energy to be deduced. Elliott's results are shown in figure 2. It will be seen that there are, first, a continuous distribution of Compton electrons due to the scattering of gamma-rays; second, two peaks corresponding to photo-electrons ejected by the gamma-rays from the K and L shells of uranium.

From the position of these peaks, the energy of the capture gamma-rays is $2{\cdot}236 \pm 0{\cdot}005$ MeV. This was checked by comparison with the Th.C^{11} line at 2·620 MeV. To this energy must be added the small energy of recoil of the nuclei on capture of the neutron. We arrive then at the binding energy of the neutron:

$$2{\cdot}237 \pm 0{\cdot}005 \text{ MeV}.$$

This is about 50 keV higher than previously accepted values, obtained from photo-disintegration experiments using gamma-rays from a van de Graaff generator, and depending therefore on accurate calibration of the generator.

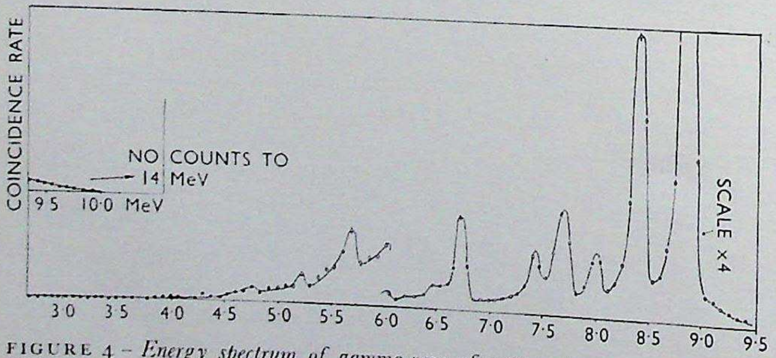

FIGURE 4 – *Energy spectrum of gamma-rays of capture in pure nickel.* (*After Kinsey.*)

Since the proton mass is tied to the deuteron mass by the mass spectrograph bracket,

$$2H_1 - D = 1{\cdot}433 \text{ MeV}$$

and $$D - (H_1 + n) = 2{\cdot}237 \text{ MeV}$$

$$n - H_1 = 0{\cdot}804 \text{ MeV}.$$

Thus the neutron mass is increased and becomes $1{\cdot}008992 \pm 0{\cdot}000010$, an increase of about 53×10^{-6}.

2. *Other experiments on gamma-ray capture*

Experiments on the energies of capture gamma-rays in other elements are proceeding and are of importance. Nuclear engineers are interested from a severely practical point of view, since they need to know the energies of the gamma-rays released from structural materials such as steel in the pile, for this affects the design of the shield.

The gamma-ray energies are measured either by the lens β-spectrometer, or, with more resolution, by a pair-spectrometer in which the positive and negative electrons created by the high-energy gammas are separately focused and the sum of their energies is measured. Figure 4 shows results obtained by B. B. Kinsey [6] at Chalk River on the energy spectrum of the gamma-rays of capture in pure nickel.

3. *Neutron reactions*

The intense source of thermal neutrons facilitates the study of slow-neutron reactions.

An interesting example is the reaction:

$$B^{10} + n = Li^{7x} + \alpha$$

An excited nucleus of Li is formed, and this gives rise to the well-known gamma-ray of 478 keV energy. When this line is observed in the β-spectrometer it is seen to be broad in comparison with the photo-electron lines ejected from a thin gold radiator by other gamma-ray lines of similar energy. The broadening can be explained by the Doppler effect due to emission of the gamma-rays by the Li^{7x} nucleus in flight. Since the nucleus is in flight for 3×10^{-13} second it follows that the gamma-rays must be emitted in less than this time. By mixing different materials with the boron target, the Li^{7x} nucleus can be slowed down more rapidly, and in this way Elliott and Bell [7] have found that its lifetime is 3×10^{-14} second.

The Harwell pile has been used to show that He^3 can be transformed into tritium by capture of slow neutrons, and the cross-section for this reaction has been shown to be very high.

The reaction is: $He^3 + n \rightarrow He^4 \rightarrow H^1 + H^3$. This is an interesting case of a reverse reaction, for tritium, produced in nuclear reactors, is the usual source of supply of He^3 in the United States, and will be so in due course in Britain.

Flowers and Batchelor [8] filled a pressure ionization chamber with atmospheric helium, of which 1·2 in 10 million parts is He^3. The protons from the reaction were detected, and their energy was measured, by an electronic pulse analyser. Their energy and numbers were compared with the protons from the transmutation:

$$N^{14} + n \rightarrow N^{15} \rightarrow C^{14} + p.$$

The cross-section for the $He^3(np)H^3$ reaction was found to have the high value of $3700 \times 10^{-24}\ \text{cm}^2$.

4. *Neutron lifetime experiment*

An experiment of considerable theoretical interest is the measurement of the neutron lifetime being carried out by Snell [9] at Oakridge and Robson [10] at Chalk River. The neutron is expected to decay into a proton with emission of a negative electron:

$$n \rightarrow p + \varepsilon^-,$$

the electron energy being 804 keV.

Application of standard beta-decay theory leads to a predicted half-life of 20 minutes using the old mass of the neutron, and about 14 minutes using the new mass. This prediction results from the standard relation between the upper limit of the beta spectrum and the half-life.

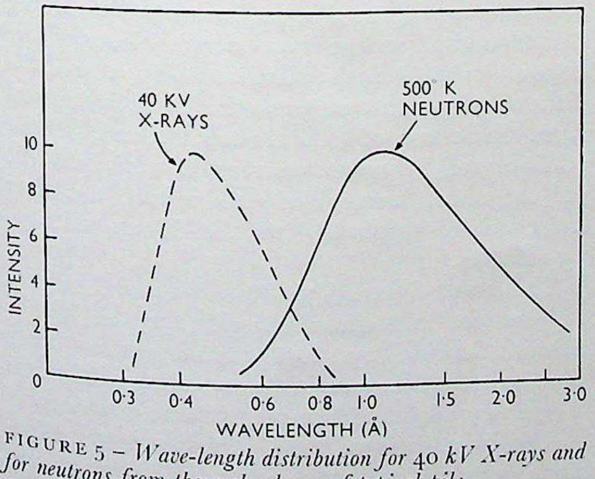

FIGURE 5 – *Wave-length distribution for 40 kV X-rays and for neutrons from thermal column of typical pile.*

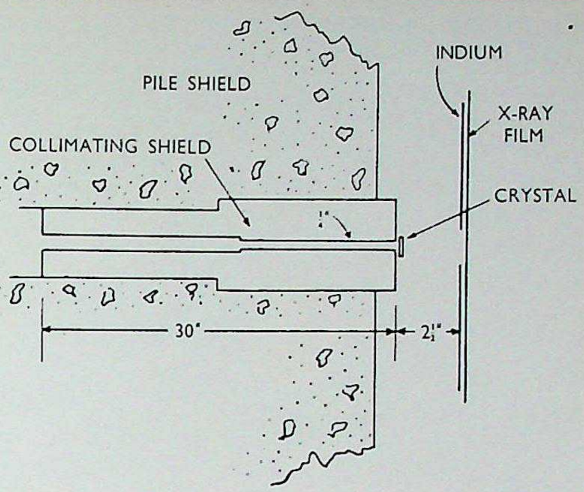

FIGURE 6 – *Method of illustrating neutron diffraction by the Laue method. (After Schull and Wollan.)*

Slow neutrons from the thermal column of the Chalk River pile are collimated into a beam of 3½ inches diameter, in which are about 10^9 neutrons per second, and pass into a vacuum chamber through a thin window. A transverse magnetic field behind the window clears the beam of secondary electrons. Inside the vacuum chamber the beam passes between two electrodes. One, cylindrical, electrode is held at + 20 kV with respect to earth. The other electrode is earthed, and forms the entrance aperture to a thin-lens magnetic spectrometer. The field between these electrodes accelerates protons which result from decay of the neutrons, so that they pass through into the lens spectrometer and are focused on the first electrode of an electron multiplier.

The background counting rate was about 60 per minute. A peak of a further 80 counts per minute was observed on top of this background when the magnetic field was adjusted for protons of an energy corresponding to 20 kV. From the number of protons recorded, the half-life of the neutron was calculated to be between 9 and 18 minutes.

NEUTRON DIFFRACTION

Neutrons, like all other particles, must be associated with waves having a wave-length

$$\lambda = \frac{h}{mv},$$

and since $m = 1{\cdot}66 \times 10^{-24}\ \text{g}$

and $v = 2{\cdot}8 \times 10^5\ \text{cm/sec at } 500°\ \text{K}$,

$h = 6{\cdot}620 \times 10^{-27}\ \text{g cm}^2/\text{sec}$

$\lambda = 1{\cdot}4 \times 10^{-8}\ \text{cm}.$

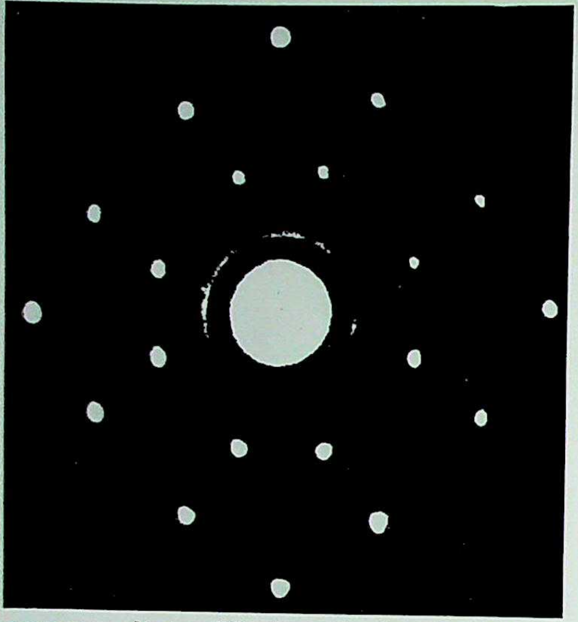

FIGURE 7 – *Neutron diffraction pattern for sodium chloride. The neutron beam is passed parallel to one of the crystallographic axes.*

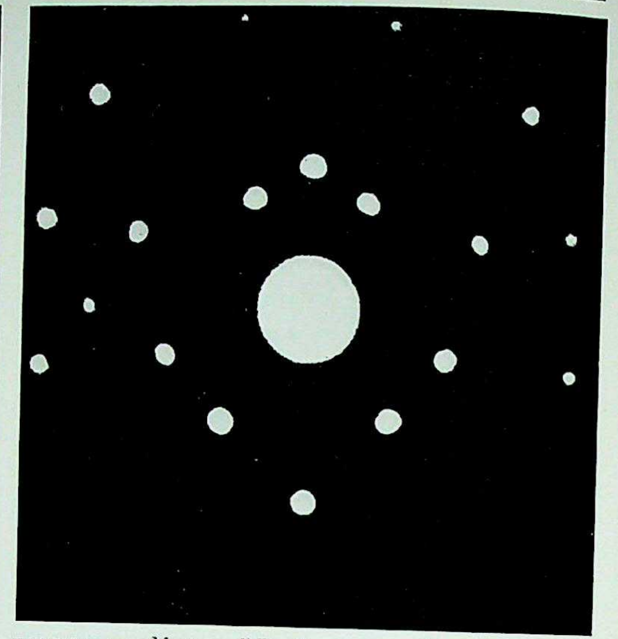

FIGURE 9 – *Neutron diffraction pattern for sodium nitrate. This is a rhombohedral crystal, and as a result the pattern is more complex than for lithium fluoride or sodium chloride.*

We should therefore expect diffraction phenomena very similar to those characteristic of X-rays.

Figure 5 shows the wave-length distribution for 40 kV X-rays, and for neutrons coming out of the thermal column of a typical graphite pile, the temperature being about 500° K. Note the important difference of sharp monochromatic lines in the copper X-ray spectrum (figure 11).

The simplest method of showing neutron diffraction in the case of a continuous wave-length distribution is by the Laue method, and figure 6 illustrates the experimental arrangement used by Schull and Wollan [11] at Oakridge to demonstrate this effect.

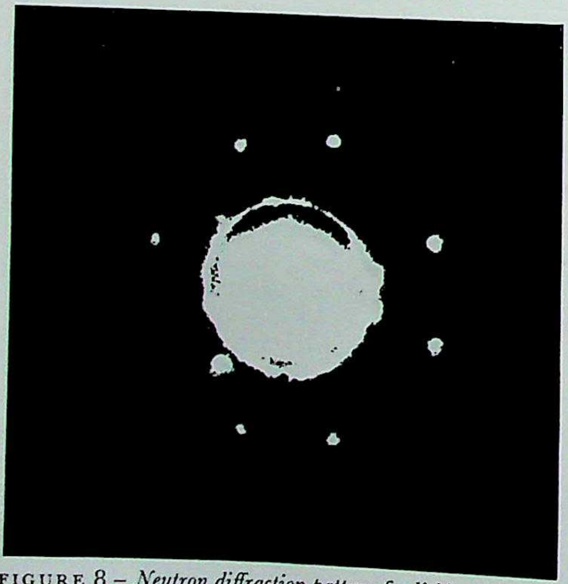

FIGURE 8 – *Neutron diffraction pattern for lithium fluoride, under the same conditions as for figure 7.*

The beam of thermal neutrons is collimated through a shield block 30 inches in length, with a final limiting aperture of $\frac{1}{4}$-inch diameter. A crystal is mounted across the beam, and the pattern is recorded on a sheet of X-ray film aligned perpendicularly to the axis of the collimated beam, with a crystal-to-film separation of $2\frac{1}{2}$ in. Since X-ray film is not sensitive to neutrons it is activated by placing an indium foil in front of it. Neutrons are captured in the indium, and produce a radioactive isotope from which electrons are emitted to darken the film at points where the diffraction pattern renders the neutron density high. Exposures of 10 hours are required, but the addition of fluorescent screen material to the indium sheet seems likely to reduce the time substantially—probably to the X-ray time of 15 minutes.

The next figures (7, 8) show the observed pattern for a sodium chloride crystal and a lithium fluoride crystal, when the neutron beam is passed parallel to one of the crystallographic axes. These crystals have face-centred cubic lattices.

The inner ring of spots corresponds to reflections from planes (3,1,1) and their permutations.

The outer ring of spots corresponds to reflections from planes (4,0,2) and (4,2,2) and permutations. Figure 9 shows the pattern from a rhombohedral crystal of sodium nitrate, which is more complicated.

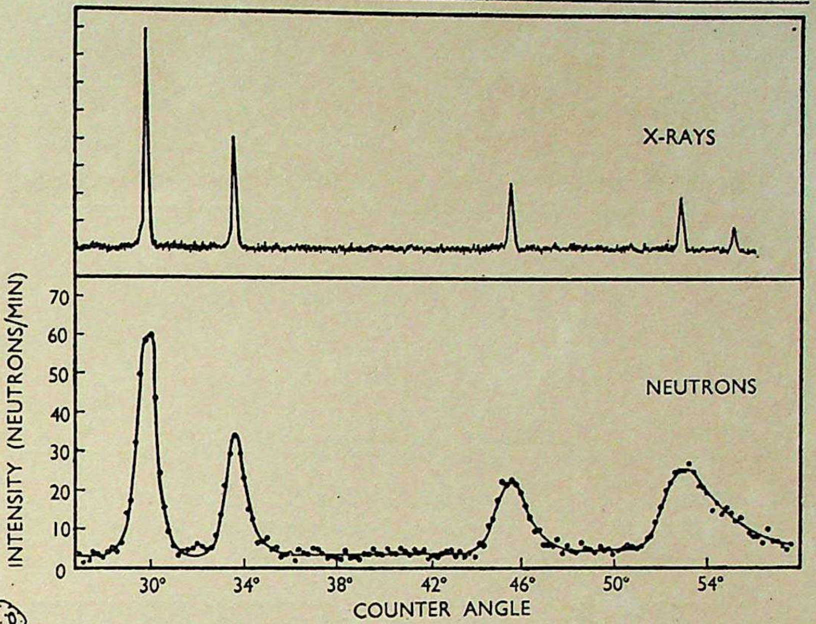

FIGURE 11 – *Comparison of results of powder diffraction with X-rays and with neutrons, by copper powder.*

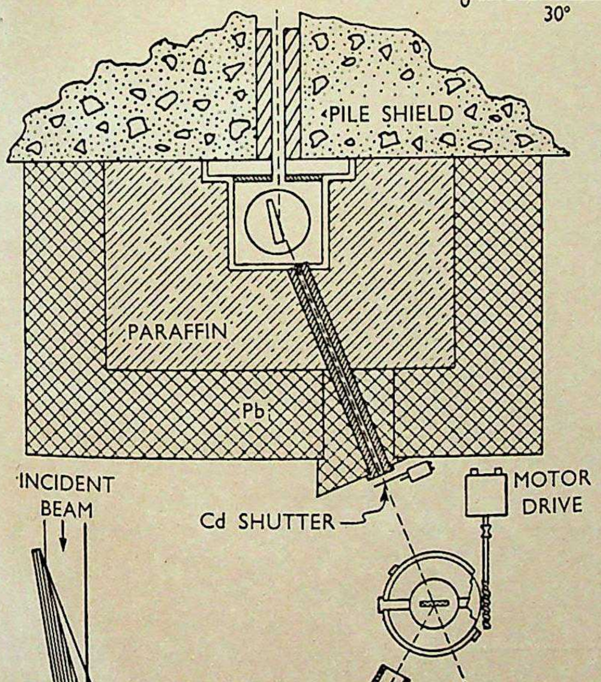

FIGURE 10 – *Neutron diffraction by the Debye-Scherrer powder method. A monochromatic neutron beam is obtained by Bragg reflection from a single crystal.*

DIFFRACTION OF CRYSTALLINE POWDERS

The most useful technique in the application of neutron diffraction is the Debye-Scherrer powder diffraction method [12], in which a crystalline powder is irradiated with monochromatic neutrons obtained by Bragg reflection from a single crystal. Figure 10 illustrates the method, and figure 11 shows the comparative results obtained with X-rays and neutrons for copper powder. It will be seen that the resolution obtained by neutrons is less than with X-rays. The intensity of the X-ray lines decreases for higher angles, owing to the decrease in form-factor, whereas no such decrease occurs for neutrons.

Figure 12 shows the results obtained for manganous oxide. In this case there is a great difference in the pattern of the peaks, owing to the negative scattering of neutrons by manganese nuclei as compared with oxygen nuclei. With X-rays the scattering is in the same phase.

In these two cases neutron technique does not add to our knowledge of structures, but figures 13 and 14 illustrate cases where neutron diffraction can supply additional information. Figure 13 shows the diffraction pattern obtained with sodium hydride. The X-ray pattern is characterized only by the sodium positions, which take up a face-centred cubic structure. The difference between the X-ray and neutron patterns is due to the hydrogen, and a detailed examination shows that the hydrogen positions are similar to those of the chlorine in sodium chloride.

The second example is the study of alloys, where the form-factors of the components with X-rays are so similar that it is not possible to pick out the position of the components. Consider the structure of an iron-cobalt alloy. Figure 14 shows

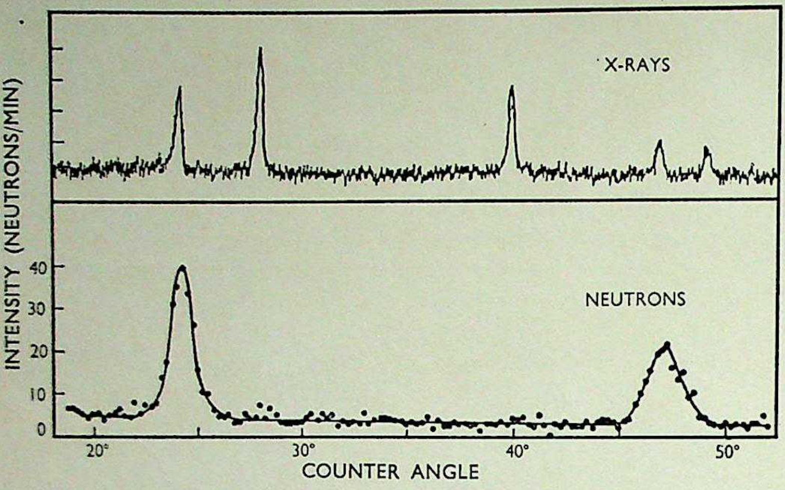

FIGURE 12 – *Comparison of results of powder diffraction with X-rays and neutrons by manganous oxide.*

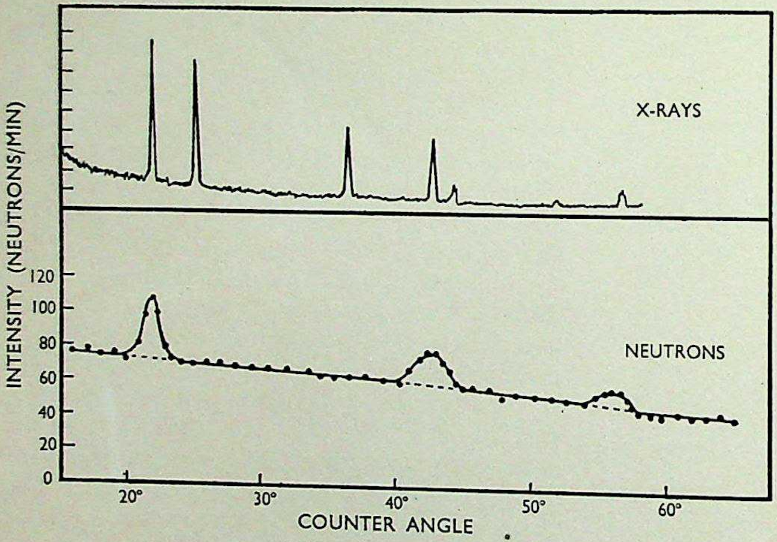

FIGURE 13 – *Diffraction patterns for sodium hydride.*

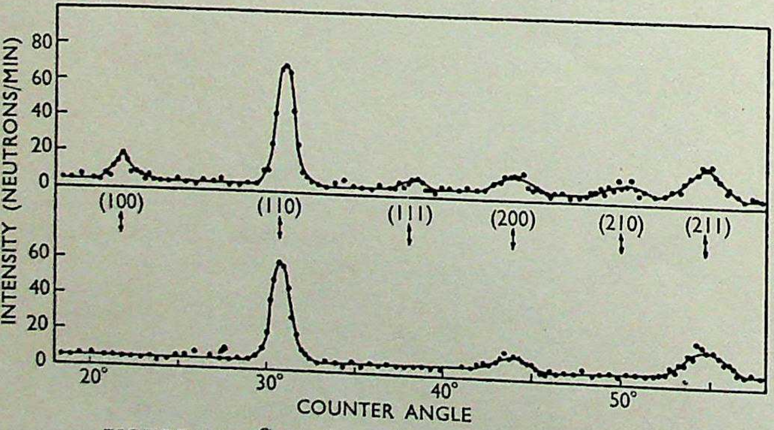

FIGURE 14 – *Comparison of neutron diffraction patterns for ordered (above) and disordered (below) iron-cobalt alloy.*

the neutron pattern for an ordered Fe/Co alloy, and the different pattern for a disordered alloy. In the ordered structure the cobalt atoms are at the centres, and the iron atoms at the corners, of single cubes.

In general, it would appear that neutron diffraction is likely to make substantial contributions to studies of metal structure. The disadvantages of the method are due to the rather lengthy time required to obtain readings, and to the fact that we cannot have atomic piles in every laboratory. We do hope, however, to make facilities available at Harwell for such studies.

THE EFFECT OF NEUTRON IRRADIATION ON SOLIDS

When fast neutrons from fission pass through crystalline material, they lose energy by elastic collisions with the lattice atoms. The result of these collisions is to displace the atoms from their position in the lattice to interstitial positions. Thus, it has been calculated that a 2 MeV neutron in the course of being slowed down to thermal energies would displace about 500 atoms in beryllium metal, and about 2500 in beryllium oxide.

The result of this action is to change the physical properties of the medium; in particular the electrical and thermal conductivities are altered and the elasticity and mechanical properties change.

We are interested in these phenomena from the point of view of pile technology. We are also interested from a more fundamental point of view. In particular we should like to be able to study the history of the displaced atoms, and to see whether or not they return to holes left by displacement of

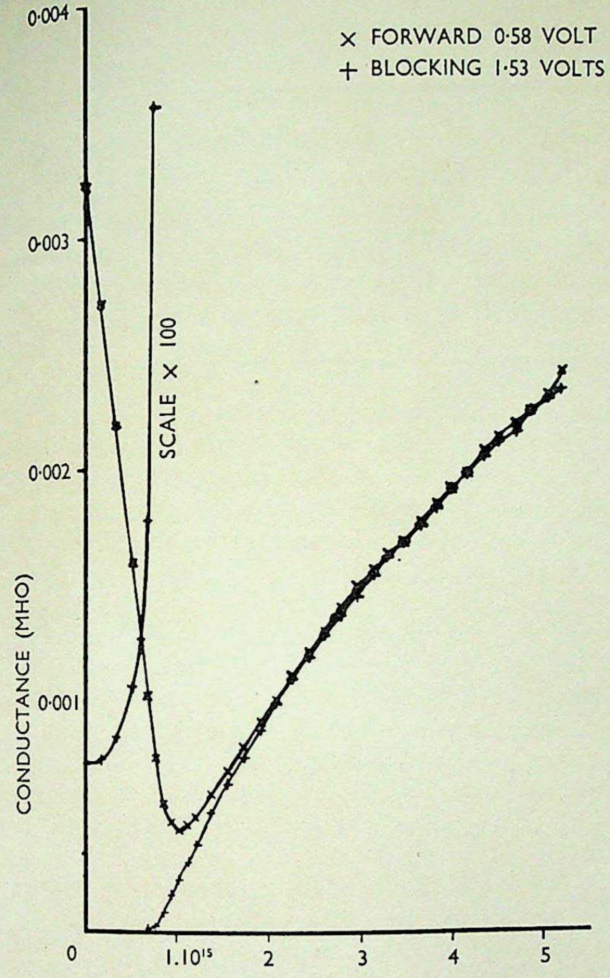

FIGURE 15 – *Effect of neutron irradiation on the conductance of a germanium rectifier at 40° C.*

other atoms, and how this process is affected by temperature.

These studies have been started at Harwell by irradiating the rectifying modification of germanium in the pile. Similar and earlier experiments have been carried out by Lark-Horovitz [13].

The properties of the rectifier are characterized by the conductivity in the forward and in the backward (or blocking) directions. In semi-conducting germanium the forward conductivity at a temperature of 40° C will be about 0·003 reciprocal ohm, while in the blocking direction it will be of the order of 10^{-5} reciprocal ohm. One of these semi-conductors was irradiated in GLEEP for a period of about a day. Any change would presumably be proportional to the time × neutron-flux at the position of the specimen, and proportional therefore to *nvt*, where *n* is the number of neutrons and *v* the velocity. One day's irradiation in the centre of GLEEP corresponds to a value of *nvt* of about 10^{15}.

The results of this experiment, carried out by T. M. Fry at Harwell, are shown in figure 15. It will be seen that the forward conductivity drops by a factor of about eight to a minimum for an *nvt* value of 10^{15}, while the blocking conductivity increases by a factor of about 25, so that forward and backward conductivity become almost equal and the crystal is no longer a rectifier. It behaves now like a second type of germanium known as the P type, as distinct from the normal N type which rectifies.

These results can be interpreted on the generally accepted picture of conductivity in semi-conductors, assuming that about one atom in a million is displaced to an interstitial position. In this position they trap electrons from the conduction band and reduce the forward conductivity.

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The clocks of Christiaan Huygens

C. A. CROMMELIN

The construction of clocks occupied much of Christiaan Huygens's time throughout his life. In 1656 he invented the pendulum clock, and in 1675 he discovered the principle of the spiral-spring regulator. He also constructed a variety of other ingenious timepieces such as the *remontoire* clock. In addition he contributed notably to the theory of harmonic motions, though the calculation of the periods of some of his oscillators was impossible, owing to the limitations of mathematical theory, until very many years after his death.

It is a well-known fact that Christiaan Huygens invented the pendulum clock in 1656, and in 1675 the timekeeper regulated by means of a balance and spiral spring. The fundamental difference is that the former depends on the force of gravity, whereas the latter is independent (or nearly independent) of it. Huygens made the pendulum strictly isochronic by applying cycloidal cheeks at the top. The balance needed no isochronizing; it is isochronic in itself, and performs, like the cycloidal pendulum, strictly isochronic harmonic vibrations.

These two inventions have endured, and still form the basis of clockmaking all over the world. It is, on the other hand, not generally known that Huygens, not being sure that the pendulum and the balance would prove to be by far the best, invented and tested a number of other mechanisms with well-defined natural frequencies to regulate the timepieces; first, to improve the pendulum and the balance if possible, and, second, with a special view to the determination of longitude at sea. It is these clocks that I shall describe in this article, after a few notes concerning the life of Huygens.

Huygens was born in 1629 at The Hague, as the second son of Constantijn Huygens, a well-known poet and statesman. He studied law and mathematics at Leiden University (1645–7), continued his studies at the *Collegium Arausiacum* at Breda (1647–9), and then settled in The Hague, where he lived at home until 1666 and devoted himself entirely to his mathematical, mechanical, physical, and astronomical studies. The fruits of these years were, *inter alia*, the theory of probabilities, the laws of elastic concussion and centrifugal force, the construction of the pendulum clock (figure 2), theoretical and practical geometrical optics (lens-grinding), and the discovery of Saturn's rings and its satellite Titan.

In 1666, Huygens accepted an invitation from the French statesman Colbert to settle in Paris as a member of the newly founded *Académie des Sciences*. He lived in Paris until 1681, and these years were extremely fruitful. In 1673 Huygens published one of his masterpieces, the *Horologium Oscillatorium*, dedicated to Louis XIV, in which he describes not only his improved pendulum clock, but also very much theoretical work, including the complete theory of the rigid pendulum (moment of inertia and the centre of oscillation), the mechanical properties of the cycloid, and the theory of evolutes and involutes. This book is one of the classical works in the history of mechanics; in it Huygens laid the foundations of rigid dynamics.

In 1673, he invented his gunpowder machine—a very primitive affair indeed, more fit for demonstration than for practical use, but nevertheless involving the principle of the internal combustion engine. In 1675, he invented the balance-wheel and spiral-spring regulator of a chronometer, and in the same year he gave the general theory of isochronism and of harmonic vibrations.

The discovery of double refraction in Iceland-spar by Erasmus Bartolinus in 1670 induced Huygens to resume his optical studies. The idea of an undulatory transmission of light ripened in his mind. In 1677 he explained completely, with the aid of his now world-famous principle, the laws of double refraction, and in the following year he communicated his undulatory theory of light to the *Académie*, though he did not publish it before 1690, in a small book, *Traité de la Lumière*, his second immortal masterpiece.

In 1681 Huygens returned to The Hague. After the death of his father (1687), he lived for the greatest part of his life at Hofwijck, a small country seat at the village of Voorburg, near The Hague, but he had also lodgings in The Hague where he sometimes spent a couple of months.

His most important work during these later years of his life was, besides his work on timepieces and lens-grinding, the exact formulation of the principle of the conservation of mechanical energy—to him an axiom, and a principle which he had used often in his researches, but never enunciated clearly until 1693.

In 1695 Huygens died in his lodgings at The Hague. It was indeed well quoted of him:

> *Credo equidem, nec vana fides,*
> *genus esse deorum.*
> (*Aen. IV*, 12)

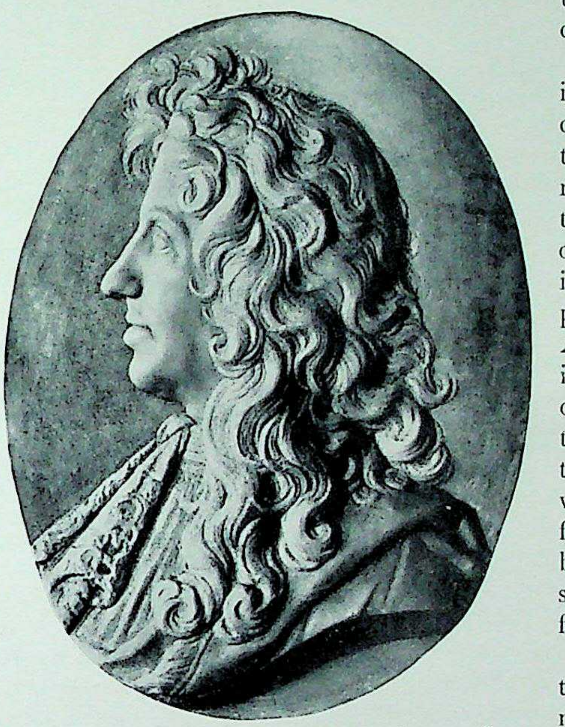

FIGURE 1 – *Christiaan Huygens at the age of 50, sculptured in relief, from real life in white marble by Jean Jacques Clérion* (1679) *at Paris.* (*National Museum of the History of Science at Leiden.*)

We have already mentioned that Huygens, during the greatest part of his life and even in the last years before his death, devoted a considerable amount of work and time to the invention and construction of all sorts of clocks.

The first one, after the invention of the pendulum clock, was a timepiece with a conical pendulum, invented probably in 1659 or 1660 and constructed about 1667 or 1668. This pendulum differs essentially from the back-and-forth oscillating pendulum. The weight describes a horizontal circle continuously; the motion of the train of gears and of the hands on the dial is also continuous; and the clock does not tick, as there is no escapement. Huygens writes in a letter (1667): '. . . *une autre manière d'horloge . . . avec un pendule qui tourne en rond*,' and in another one (1668): '*J'en ay icy une du mouvement circulaire . . . qui va assez bien et sans bruit*.'

Of this timepiece, Huygens devised two models. We know the first one only by two rough sketches in manuscripts in the Leiden university library, and by a very short and very indistinct description in the same manuscripts. There is an arrangement to make the period isochronic, i.e. in this case independent of the value of the angle of elevation, but this apparatus is clumsy rather than elegant and we shall not describe it. It has very probably never been constructed or tested.

Huygens' second isochronic conical pendulum, on the contrary, is most ingenious—even really beautiful (figure 3). The well-known formula for the period of a conical pendulum is

$$T = 2\pi\sqrt{\left(\frac{l\cos\alpha}{g}\right)}$$

in which l = length of pendulum, α = angle of elevation, and g = acceleration due to gravity. The problem is thus to construct a pendulum so that $l\cos\alpha$ remains always constant.

Huygens' construction is represented schematically in figure 6 in the text. The metallic rod XO rotates by the action of the weight or the spring of the clock. To this axis is attached at E, and supported by the metal rod XD, a metallic curve ED in the form of an evolute of the parabola FOF', so that the axis, the rod, and the curve form a rigid whole, the parabola in the figure not indicating metal but being drawn for the sake of the proof which follows.

The pendulum is attached at D. When the machine is at rest, the wire of the pendulum follows the curve and the weight is at O, but when the axis rotates, the weight is elevated by the centrifugal force to A, some point of the parabola; the pendulum adopts the form $DP'A$ ($P'A$ being tangential to the evolute and normal to the parabola), and the weight rotates with an angle of elevation α on a circle situated on the paraboloid of revolution around the axis.

When this is well understood, the demonstration of the isochronism is simple. As a matter of fact, nothing in the motion of the pendulum changes when P is fixed, so that $l = PA$, the true length of the pendulum, and thus $l\cos\alpha = PC$, i.e. the projection of the normal AP on the X axis. According to a well-known property of the parabola, this projection is constant and equals p, when

$$y^2 = 2px$$

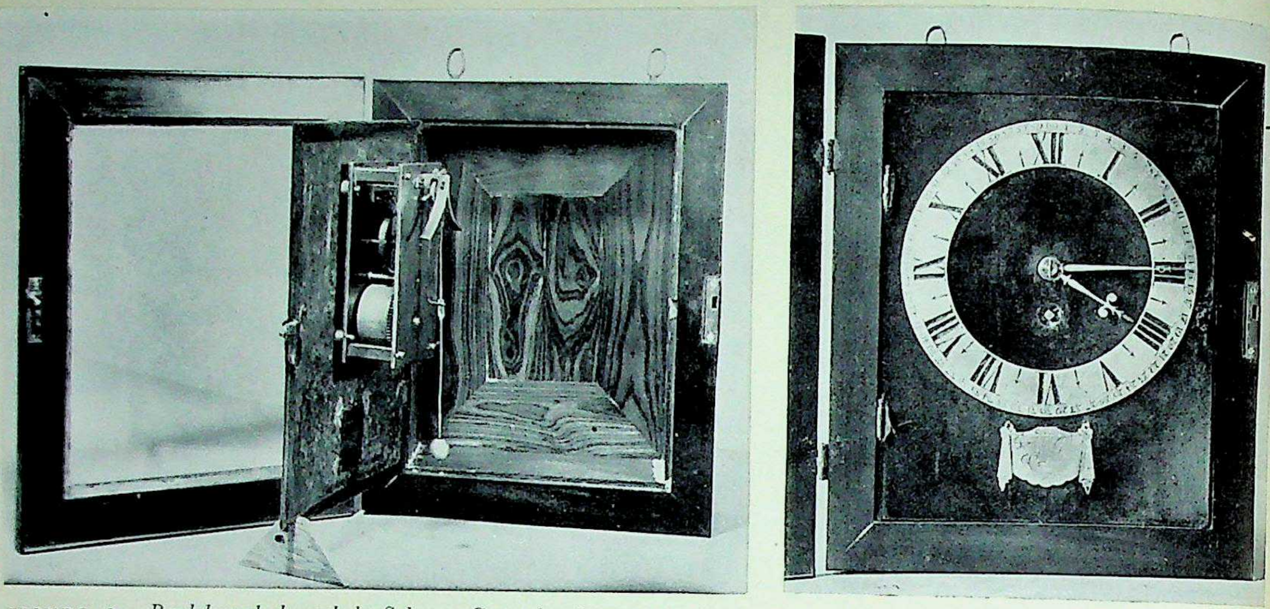

FIGURE 2 – *Pendulum clock made by Salomon Coster in 1657 at The Hague under Huygens' personal supervision. It is the oldest pendulum clock in existence. (National Museum of the History of Science at Leiden.)*

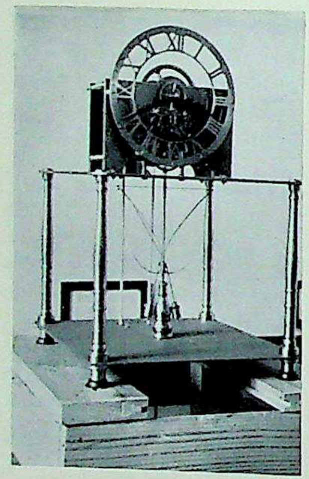

FIGURE 3 – *Reconstruction of Huygens' clock with parabolic conical pendulum. (National Museum of the History of Science at Leiden.)*

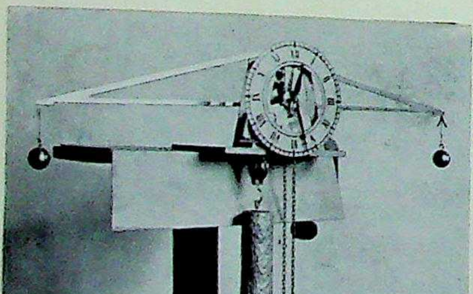

FIGURE 4 – *Reconstruction of Huygens' clock with the* Libra isochronis recursibus. *(National Museum of the History of Science at Leiden.)*

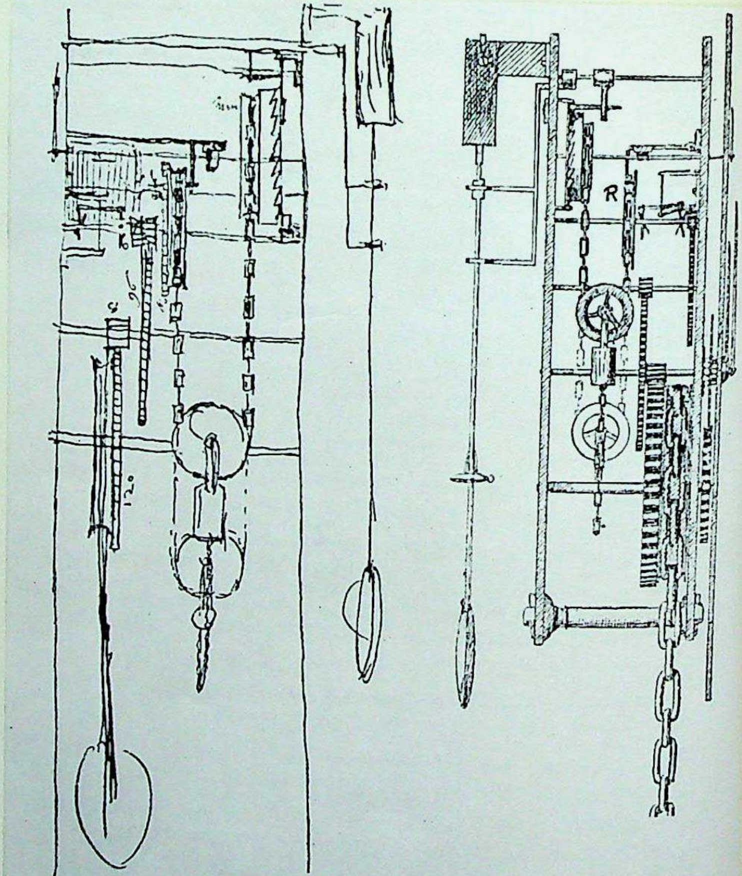

FIGURE 5 – *Marine* remontoire *clock, drawings by Huygens. (From the manuscripts in the Leiden University Library.)*

is the equation of the parabola. Hence it is proved that the period

$$T = 2\pi\sqrt{\left(\frac{l\cos\alpha}{g}\right)} = 2\pi\sqrt{\left(\frac{p}{g}\right)}$$

is constant and independent of α.

We have already mentioned that Huygens always had in mind the determination of longitude on board ship by means of his newly invented pendulum clock, but such a clock requires a very firm and steady mounting, which of course cannot be achieved on board ship All trials of a pendulum clock on a sea voyage proved to be failures, but Huygens, notwithstanding those failures, continued all his life to design new models of pendulum clocks intended for use at sea.

The first model is the *remontoire* clock of 1664, which, as R. T. Gould says with good reason, 'includes some of the most ingenious, elaborate, beautiful, and useless contrivances ever made by man.'[1] The short pendulum (with cycloidal cheeks) swings, not under the action of the driving weight, but under that of a very small weight in the interior of the clock, the train of gears and the hands on the dial being at rest (figure 5). Every half-minute, contact between the pendulum and the train of gears is established by an automatic device (too complicated to be described here); the small weight is remounted very rapidly by the driving weight; and the cogwheels begin to turn, but only just enough to advance the hour hand and the minute hand for half a minute. Then the action begins again, and so on for every half-minute.

The advantage of the *remontoire* consists in the fact that the pendulum swings under the action of the small weight, and is connected with the escapement only by means of the crown wheel. Its period is thus entirely independent of any irregularities in the train of gears, and of the thickness of the oil, etc., the only function of the main weight and of the train of gears being the rapid rewinding of the small weight each half-minute. It is, however, difficult to understand Huygens' strong recommendation that *remontoire* be used on board ship, for its complicated mechanism renders it most unsuitable for this purpose.

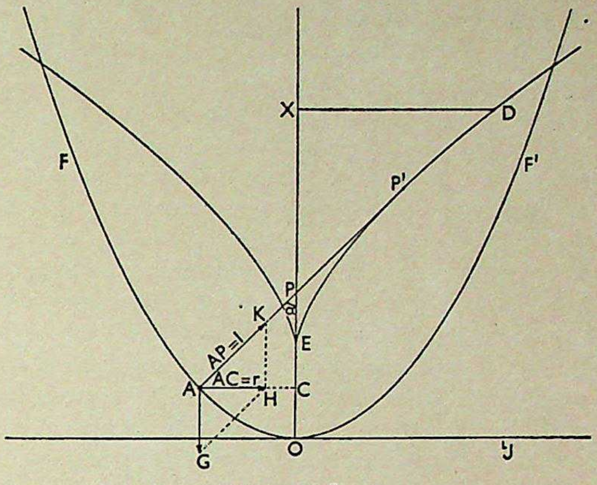

FIGURE 6

Huygens' second model was the marine clock of about 1672 (figure 7). This clock was spring-driven and had three dials, a big one for the minutes, and two small ones inside the big one for the hours and the seconds. It was suspended in gimbals (Cardan suspension) in order that it should not follow the movements of the ship. At the bottom of this suspension was a heavy leaden weight for purposes of stabilization. The lens-shaped weight of the pendulum was suspended on two thin wires, both with cycloidal cheeks at the top, so that it had the form of a V.

In 1675 Huygens invented a timepiece regulated by a balance-wheel and spiral spring, i.e. a timepiece independent (or nearly independent) of the force of gravity and its direction. This invention is sometimes attributed to Robert Hooke, the well-known secretary of the Royal Society, but in my opinion unjustly. Hooke contested Huygens' priority; he spoke of his 'watches regulated by springs,' but, as far as I know, never described the nature of his springs, or the way in which they were attached to the balance.[2] It should be noted

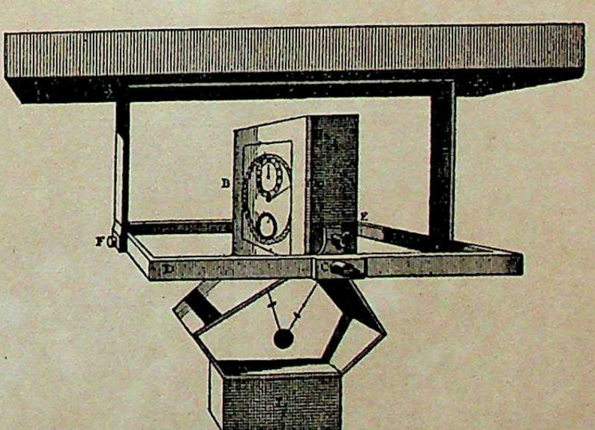

FIGURE 7 – *Marine clock with pendulum suspended on two wires. (From a drawing in Huygens'* Horologium oscillatorium.)

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[1] R. T. Gould. *The Marine Chronometer*, p. 28 (London, 1923).

[2] R. Hooke, Cutlerian Lectures, reprint by R. T. Gunther, *Early Science in Oxford*, vol. VIII.

that the spiral spring is the only one that has been kept in use for chronometric purposes up to the present day; it is harmonic and isochronic, properties of which Huygens was well aware.

Huygens soon observed that the characteristic period of the spiral spring was influenced in a high degree by the temperature—much more so than that of the pendulum—and this was the reason why he did not continue his experiments on the balance spring, compensation devices being totally unknown at that time.

Wanting to keep the balance movement but to get rid of the spring, he invented a suspension of the balance by means of three threads; he called this pendulum the *Pendulum cylindricum trichordon*. When the balance (a rather heavy hollow cylinder) is moved from its dead-point, it is slightly raised, and the threads are deviated from their original vertical position. If then left to itself, the balance performs a to-and-fro rotating movement. The clocks with this pendulum were again designed for marine use; they were constructed about 1685 and were probably put to the test by Huygens himself on the Zuyder Zee. It is difficult to understand why Huygens returned here to a pendulum swinging under the action of the force of gravity, which he had avoided carefully in the case of the balance and spring.

Notwithstanding all the failures of the pendulum clocks on board ship, Huygens never gave up all hope of success in this matter, and even in the last years of his life he invented several new models of pendulums for marine use.

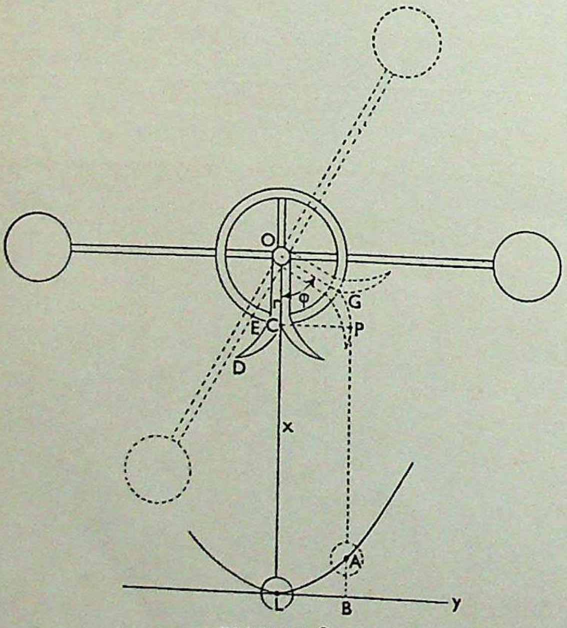

FIGURE 8

Very interesting is what he calls the *Libratio isochrona melior praecedente* of 1693 ('the isochronic balance better than the previous one,' this previous one being a simpler model not described here). It has never had any practical value, but the mathematical demonstration is very elegant (see figure 8). A large and heavy balance swings slowly on a horizontal axis, under the action of the force of gravity. Rigidly connected with the balance is a vertical rod OC, with two cheeks DE, not cycloidal, but of the form of an involute of the circle with radius $r = OC$. Between the cheeks in C a string is attached bearing the weight L; this string with its weight is not a pendulum, and remains (or is supposed to remain) in a vertical position when the balance swings. The balance with the rod, but without the weight L, is supposed to be in indifferent equilibrium; with the weight L, but without the cheeks, it would be a rigid pendulum and thus approximately isochronic. The cheeks make the swingings strictly isochronic.

To prove this theorem, we first calculate the trajectory which the weight will describe when the balance swings. P, the point where the spring detaches itself from the involute GP, remains always at the same height as C, CP being tangential to the circle and normal to the involute. Now

$$\text{arc } GP = \frac{CP^2}{2r}$$

(found by integration, the equation of the involute being given).

Taking OL as X axis and LB as Y axis, arc $GP = AB = x$, and $LB = CP = y$, therefore

$$x = \frac{y^2}{2r}, \text{ or}$$

$$y^2 = 2rx.$$

The trajectory of L is thus a parabola with r as parameter.

The moment, M, of the force which the weight exerts on P is

$$M = mgCP = mgy$$

(m being the mass of the weight);

$$y = CP = \text{arc } CG = \varphi r,$$

thus

$$M = mg\varphi r;$$

φ being the angle of rotation of the balance, we have

$$\frac{M}{\varphi} = mgr = \text{const.}$$

Therefore the swingings are harmonic and strictly isochronic.

Figure 4 represents an improved model of the latter clock, which Huygens calls the *Libra isochronis recursibus*. A long but very light triangular balance swings slowly; at both ends weights are attached, by means of strings, between arcs of the form of involutes of a circle. This timekeeper was doubtless an improvement, from a technical point of view; its oscillations are also strictly isochronic, but the proof of the isochronism is rather complicated and too long to be given here.

The mathematical proofs of isochronism as I have given them in two cases are modern, and not in the form in which Huygens gave them. Huygens knew quite well the methods of Descartes' analytical geometry and used them when necessary, but he preferred pure geometrical proofs. Most of his innumerable mathematical and mechanical demonstrations were purely geometrical: always most ingenious, generally not easy to read, and always cumbersome—from a modern point of view at least.

It is noteworthy that Huygens never mentions or calculates the periods of his sometimes rather complicated swinging systems, and there is every reason to believe that he was unable to do so, simply because the mathematical methods of his time were inadequate.

Nowadays we calculate all such periods by an ingenious and simple theorem which holds for all swinging systems, the swings of which are harmonic and the position of which can at any given time be defined by one single parameter ψ.

In this case, the potential energy E_p and the kinetic energy E_k can always be written as follows:

$$E_p = \tfrac{1}{2}A\psi^2 \quad \text{and} \quad E_k = \tfrac{1}{2}B\left(\frac{d\psi}{dt}\right)^2,$$

A and B being constants independent of the time. The period is then

$$T = 2\pi\sqrt{\frac{B}{A}}.$$

The proof of this theorem may be easily given by substituting a harmonic function for ψ, for instance:

$$\psi = \cos\frac{2\pi t}{T}$$

and by introducing the condition that

$E_p + E_k =$ const., i.e. independent of time.

By means of this theorem one finds, for instance:

For the simple cycloidal pendulum:

$$T = 2\pi\sqrt{\frac{4r}{g}}$$

(r being the radius of the circle which generates the cycloid);

For the pendulum cylindricum trichordon:

$$T = 2\pi\sqrt{\frac{Ql}{mgr^2}}$$

(l being the length of the strings, r the radius of the balance and Q the moment of inertia of the balance);

For the libra isochrona melior praecedente:

$$T = 2\pi\sqrt{\frac{Q}{mgr}}$$

(identical with period of the rigid pendulum).

This theorem is extremely useful in calculating such periods; it holds also in many other cases, for instance for a liquid oscillating in a U-shaped tube, and even for electrical oscillations.

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Amber inclusions

G. KIRCHNER

Amber inclusions are of exceptional interest to the palaeontologist, for no other natural form of prolonged preservation leaves the specimens in such perfect condition. In recent years their significance has increased as a result of the discovery of large numbers of aquatic forms, formerly regarded as being very rare. It is therefore a cause for profound regret to learn that the unique collection of amber acquired by the University of Königsberg—much of it derived from the famous Palmnicken amber mines—was destroyed during the last war.

The trees which exuded amber were conifers, but they have long been extinct. They bequeathed their hardened resin as a yellow stone-like substance, which so often contains relics of early forms of life that it has claims to be considered the best of all natural preservatives. While calcite, pyrites, and flint have also transmitted to us interesting forms of prehistoric life, these media modified the captured bodies through diagenesis, and thus more or less changed their original appearance. Amber resin, however, was completely innocuous, and it began to solidify almost immediately after the engulfment of an object. During the short period of its existence in the liquid state it offered little resistance to intrusion, whether by insects, by feathers carried into it by the wind, by leaves and other parts of plants, or by small bodies in general. Even water could be engulfed to a certain degree, as has been proved by the discovery of inclusions of aqueous origin.

Until recently, the amber inclusions generally known originated from the fauna and flora of the subtropical land where the amber trees grew in mixed forests. It may be assumed that several different types of conifers provided similar resins, but, although many trees of geologic age are known to us in detail, we have very few indications as to the appearance of the amber conifers. Their only traces are the small inclusions of flowers, wood splinters, needles, and twigs, which, though confirming types, do not reveal much about the actual identity of the trees.

The problem has been widely studied, but it cannot be said to have been solved. It is perhaps true that palaeobotanists have not yet fully considered the suggestion that amber trees may have been swamp-trees related to the Tertiary swamp-cypress. This possibility is now being investigated, partly because twigs of cupressoids appear more frequently among amber inclusions than the needles of firs and pines, and partly on account of the large variety of aquatic inclusions recently discovered.

The amber collection of Königsberg University—unhappily destroyed during the war of 1939–45—contained a vast number of animal inclusions, and numerous specimens containing arthropods (insects, centipedes, spiders, etc.) had been collected through decades in the amber works in the neighbourhood, where raw amber was treated. The few cases in which aquatic animals were found among the inclusions were, however, believed to have been caused by fortuitous circumstances, and the idea that they might have resulted from the resin entering the water, and there engulfing the animal, had not been conceived.

This conception took shape after repeated observations in the well-known amber works at Palmnicken—where numerous and frequently recurring specimens of this type were discovered—provided overwhelming evidence that aquatic inclusions could not be the result of accidental occurrences. It was found that aqueous inclusions originated both in the sea and in fresh water, and those discovered are by now quite as numerous as the terrestrial ones.

Little information has so far been obtained about the vegetative and physical processes which led to the hardening of the resin, and no complete chemical analysis of amber has been achieved. If amber could be melted without decomposition, the process of solidification could be followed, and perhaps experimentally controlled. At present, any conclusions about the possible properties of the liquid form have to be based on investigations of the solid, for this, on heating, decomposes into the so-called oil of amber and a black, pitch-like residue. On dry distillation, amber yields from 3 to 8 per cent. of succinic acid. It is probably not a single chemical individual but a mixture of various resinous substances with a chemical constitution approximating to $C_{10}H_{16}O$; it also

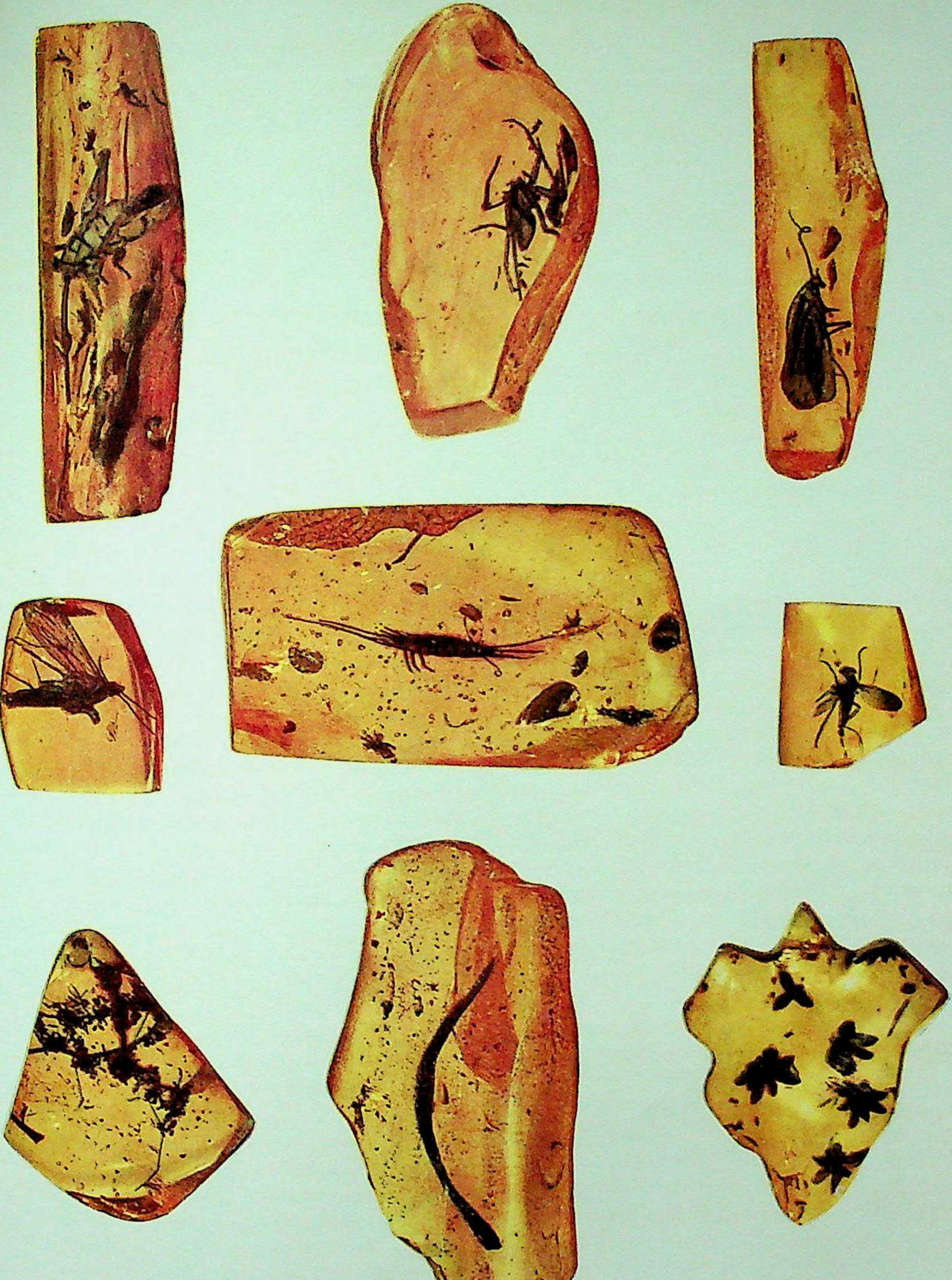


PLATE I – *Specimens of plant and animal inclusions in amber.*

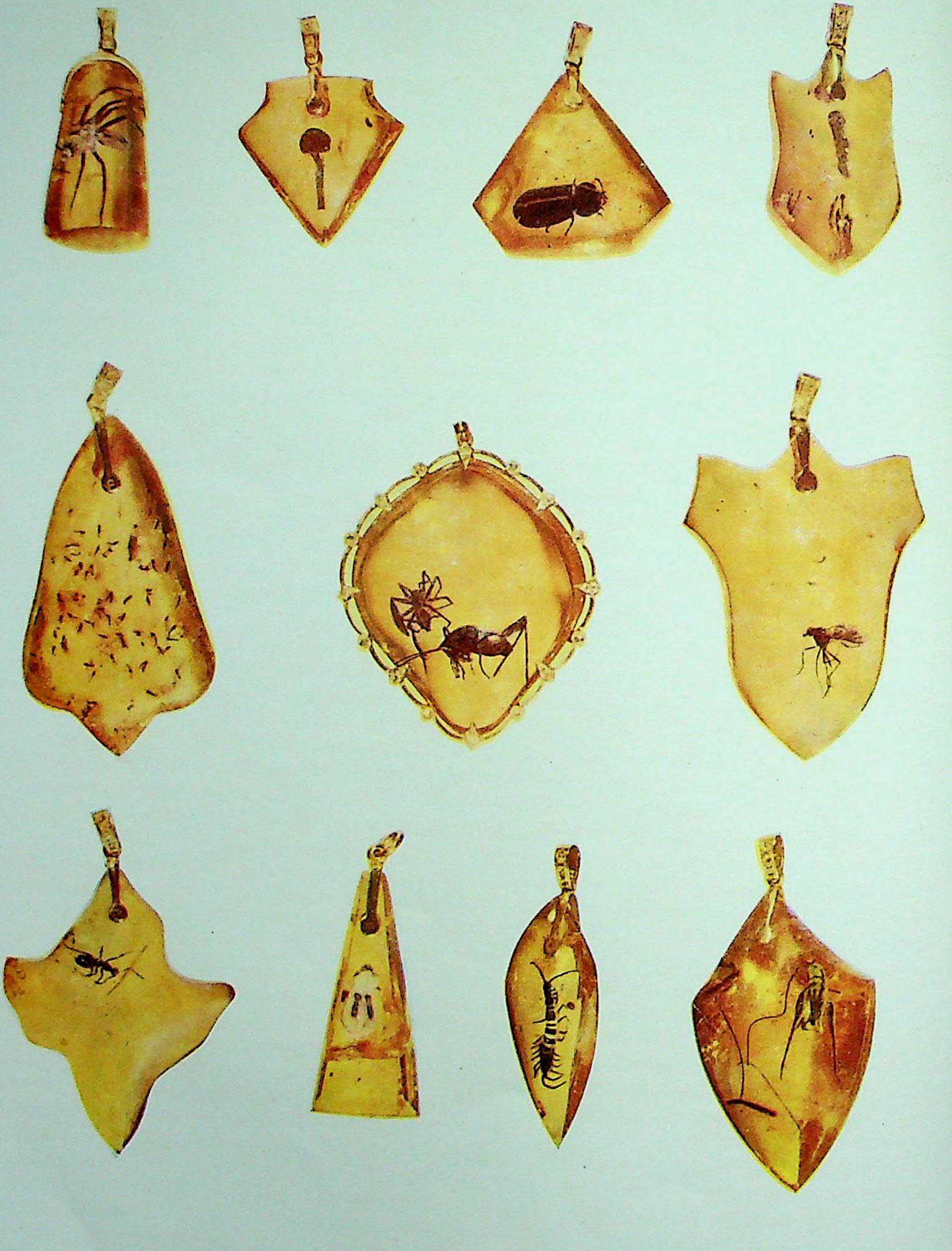


PLATE 2 – *Specimens of plant and animal inclusions in amber.*

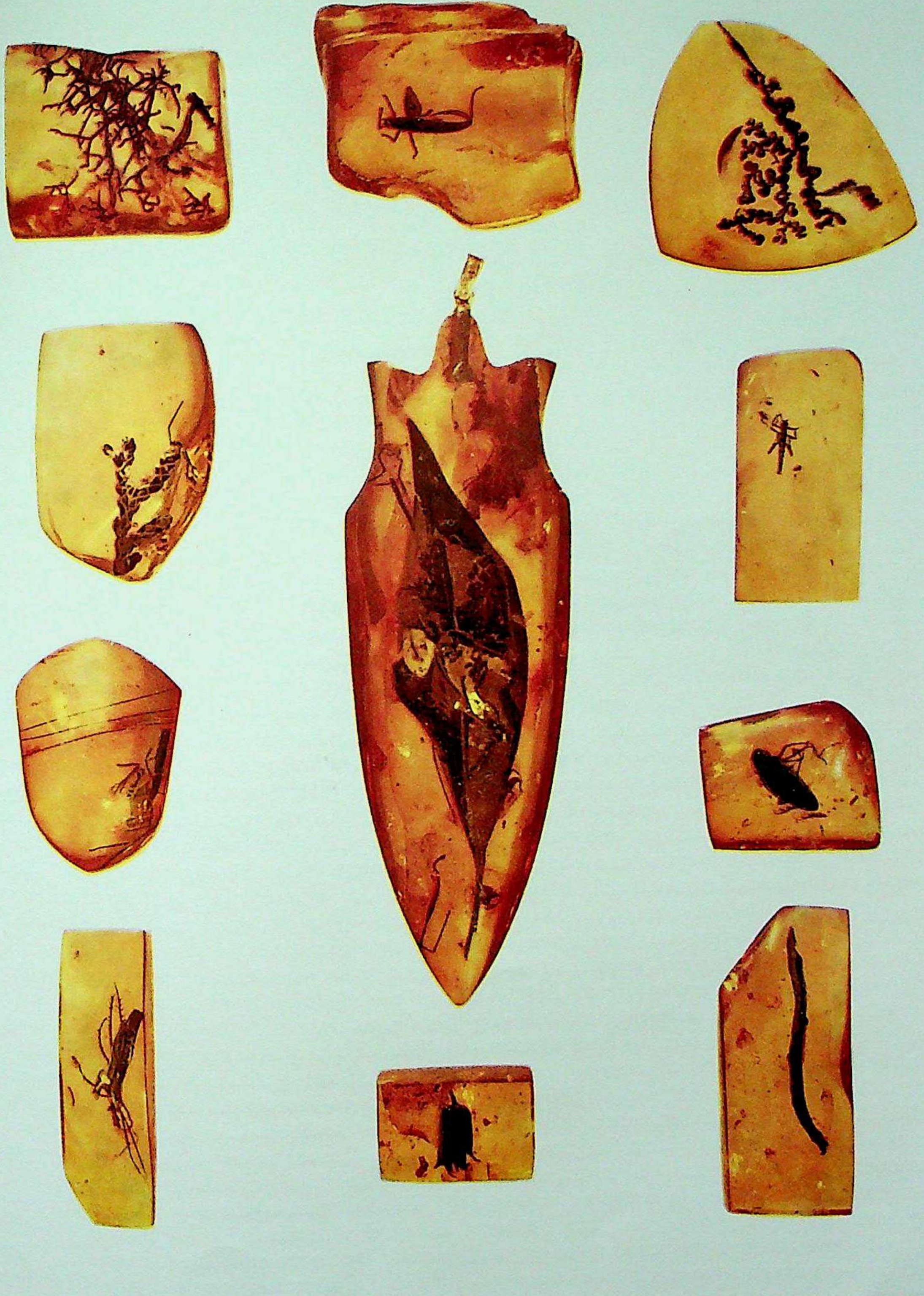


PLATE 3 – *Specimens of plant and animal inclusions in amber, including some aquatic forms.*

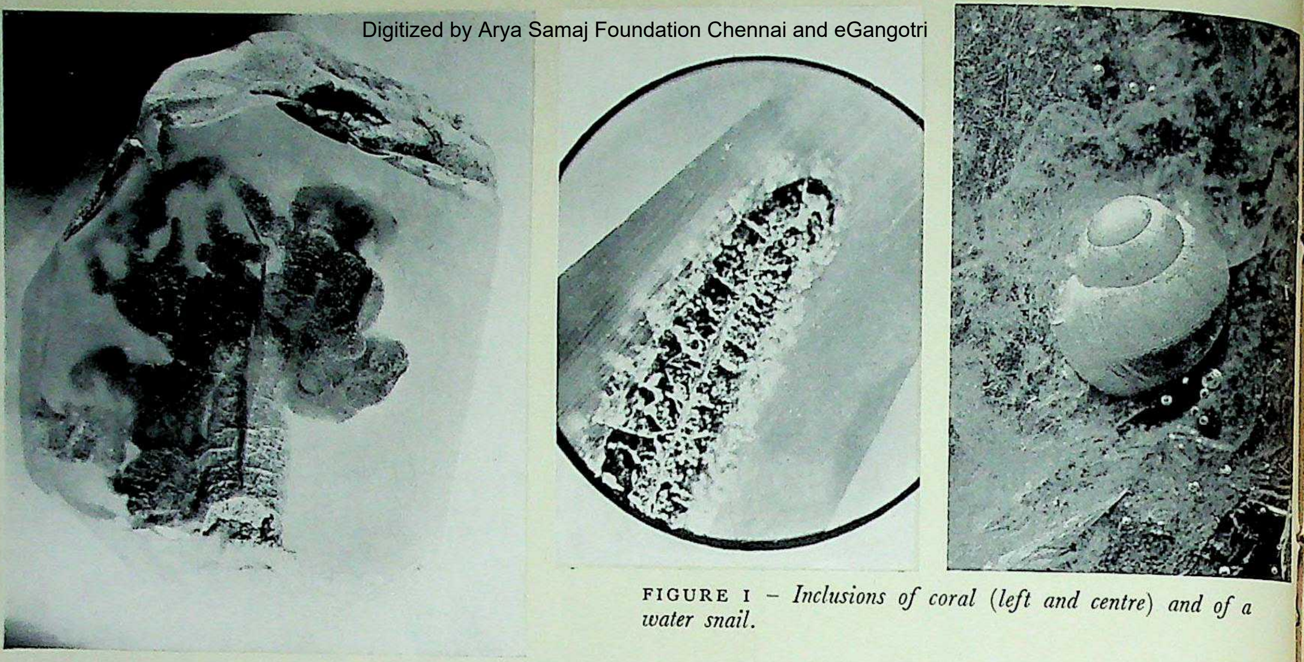


FIGURE 1 – *Inclusions of coral (left and centre) and of a water snail.*

contains small amounts of inorganic compounds such as the chlorides and sulphates of calcium and magnesium. In the case of aqueous inclusions, these salts may well have been introduced in the water.

The resin which flowed from the cells of the woody tissues was a quasi-living substance, and the masses of it which spread outside (usually 1–3 kg but exceptionally 6–9 kg), to cover a wound in the tissue, solidified under unknown conditions. A fact of which we can be certain is that the solidification must have taken place rapidly; the resin was thus able to transmit to us the unaltered appearance of the animal or plant which happened at that moment to be in contact with it. The inclusions, especially when total, are intact, and have been preserved in their natural form. If the quantity of the flowing resin was insufficient, the object remained in the border of the hardening mass. The opening thus left resulted in atmospheric oxidation, causing a reddening of the resin, and small cracks would develop as the amber weathered. These might influence the transparency of the matrix. Inclusion of large numbers of minute air bubbles renders amber turbid.

X-ray examination has shown that amber is amorphous. Its specific gravity is usually between 1·06 and 1·08, though somewhat lower and higher figures have been recorded for occasional specimens. The specific gravity of the liquid balm was possibly lower than that of the solid, and the surface tension was doubtless low. Owing to its greater density, the liquid would sink in water, and this explains the inclusions of such organisms as *Volvocales*, *Cyanophyceae*, *Protococcaceae*, and radiolarians; even drops of water were sometimes included in smooth-walled cavities. Water was not absorbed during the process of solidification, and the drops in amber have therefore been preserved for countless thousands of years. It has also been observed that the vacuoles in enclosed plankton algae are still filled with the aqueous liquid which they contained when the algae were alive. It would be an interesting task for further amber research to subject these liquids to a microchemical analysis; among other things such research might reveal whether the sea-water of the Tertiary age possessed a similar composition to that of the seas of today.

The discovery of very large numbers of aquatic amber inclusions of an amazing variety stimulated scientists to investigate the processes leading to inclusion and solidification; this widened the scope of amber research, which had previously been focused on inclusions of terrestrial origin.

The first aim of the new investigations was to determine the miscibility with water of a material similar in character to the amber resin. The inclusion of objects of aquatic origin in the resin during its solidification could be possible only if its miscibility with water were incomplete. A familiar example of incomplete miscibility is provided by the system phenol-water, and as phenol is the basis of various resinous substances it seemed as good a substance to use for comparison as any other; moreover, it has the same specific gravity as amber. At 20° C, the solubility of phenol in water is 8 and the solubility of water in phenol is 28. Above 66° C phenol and water are completely miscible. The maximum temperature of the water of the subtropical Tertiary sea was almost certainly not higher than 25° C, and thus, if the comparison between phenol and amber balm be regarded as allowable, we may assume that amber balm and water were in fact only partially miscible under the then prevailing conditions. Incidentally, it may be noted that the hardness of amber hardened on or in wood is much higher than that of amber with aquatic inclusions, which shows such little resistance that it often breaks when manipulated.

Aquatic inclusions usually occur in massive amber, while those of terrestrial origin appear to be found exclusively in a shaly variety of the resin. Submersion in water evidently provided conditions for solidification very different from those which prevailed for the resin in the atmosphere, where each layer hardened as it emerged from the tissues of the trunk.

The large number of specimens found in the open-cast amber works at Palmnicken provided rich material for research, and a full examination of nearly all the samples was carried out. Among them were part of the arm of a starfish, a young fish, a very good example of a polychaete, the imprint of a fish's tail, some mussels, and several corals. These discoveries brought considerable progress, but the work was still far from complete, especially with regard to evidence about haliplankton and limnoplankton, the presence of which seemed probable after the discovery of algae and corals in amber. While these could often be detected by the naked eye, plankton required thin sections of the amber for intensive microscopic examination. The results proved satisfactory in the end, but within the limited space of this article only a few of them can be mentioned.

Four stages of the amber-alga *Discophyton electroneion* could be examined in detail. The presence of this alga, belonging to the *Cyanophyceae*, offers one of the best proofs of the existence of at least one type of swamp-tree among the resin-exuding trees, for it contains the blue colouring-matter phycocyanin, which occurs freely in swamp vegetation. *Discophyton* may be reckoned the leading amber inclusion, providing as it does about 70 per cent. of all the aquatic inclusions.

With regard to size, corals and hydrocorals are of foremost importance among the marine inclusions. Hydrocorals were colony-forming polyps with a massive calcareous external skeleton surrounding the tube-shaped body; until lately they were classed with the genuine corals. Hydrocorals were exclusively marine animals and formed dense, massive reefs. Their nearest relation among recent forms is *Millepora alcicornis*. They lived in the littoral zone, not in deep water. We can imagine that amber-tree wood, cast into the sea by the wind or some other natural agency, exuded its resin on a reef near the shore. Some of the resin attached itself to the jagged rocks and hardened there, and, if not swept away by the waves, took a passive part in the fate of the reef. Sinking with the floor of the sea, the reef may have encountered water rich in iron and in hydrogen sulphide, for the hard parts of the hydrocorals in these amber inclusions show a content of iron sulphide the composition of which approximates to that of iron pyrites. It seems likely that the fragments of free iron pyrites which occur in some amber mines are remnants of the pyritized hydrocoral reefs of the Tertiary sea.

Genuine corals are represented by several types. They are closely similar to the present red coral of the Mediterranean in the formation of their branches and skeletons. Their tentacles are not feathered but smooth, though they show the octagonal arrangement of the octocorals. The tentacles of the specimens in some of the inclusions are partly fully extended, partly withdrawn as in defence. The preservation of the very sensitive tentacles of the living coral indicates the rapidity with which the engulfment took place; any biologist would have to work extremely quickly to achieve a similar preservation.

A specimen of *Carophyllia turbinolida* is of special interest. This coral builds solitarily and is shaped like a closed cup. Its identification was possible only because one of the cups had apparently been split open accidentally and thus presented itself to investigation as if a special section of it had been made.

Until recently, the inclusions of terrestrial origin had provided the principal contribution to the natural history of amber. New problems have arisen through the discovery of aqueous inclusions, and the solution of these problems will lead to a wider and fuller knowledge of the geology of the amber formations of the Samland.

The Arabic achievement in physics

H. J. J. WINTER

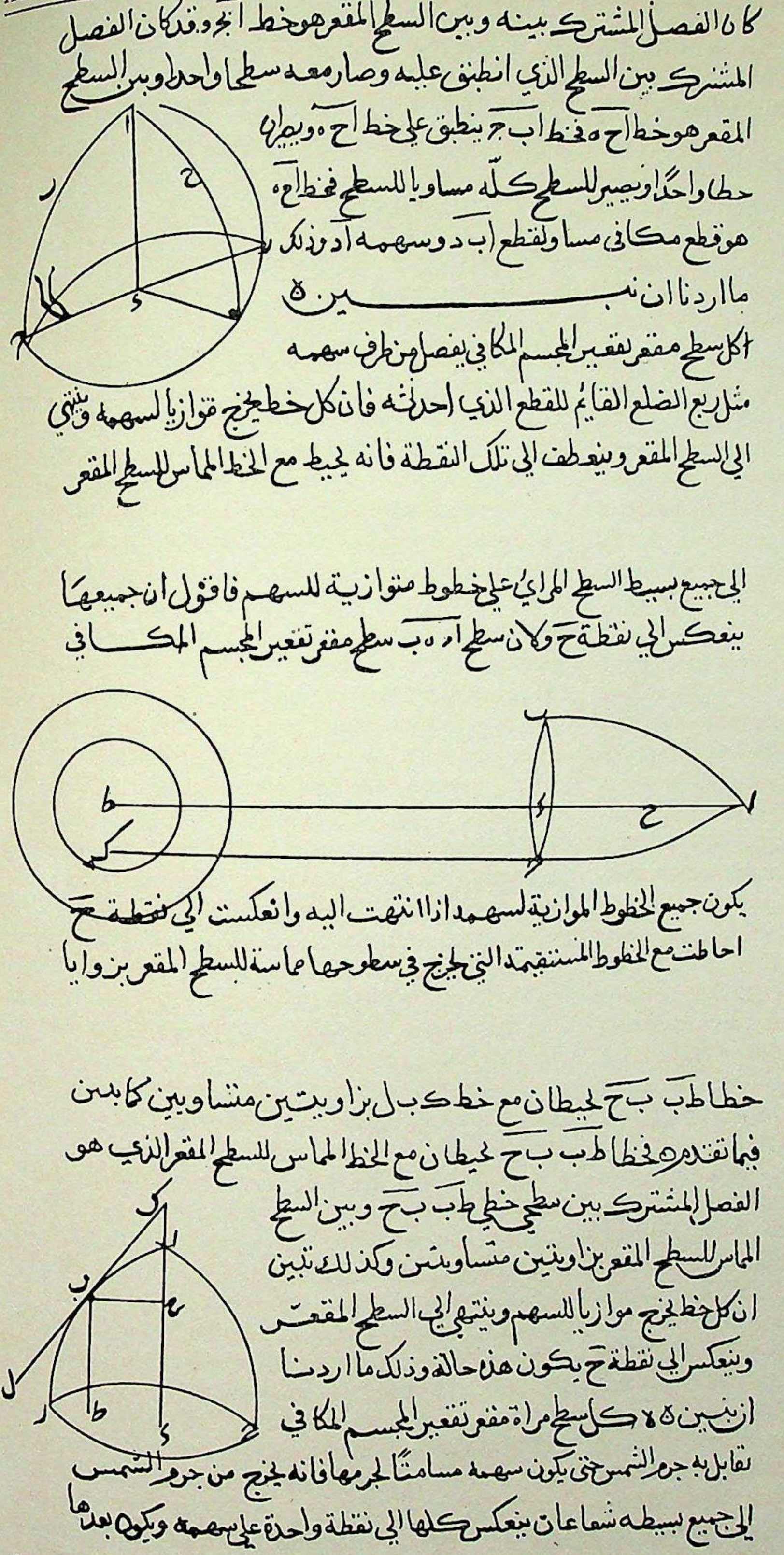
Arabic contributions to chemistry are widely known and appreciated; it is, however, much less generally realized that there was also a notable Arabic contribution to astronomy and to physics, especially in optics, mechanics, and hydrostatics. With the encouragement of such patrons as Frederick II of Sicily and Alfonso X of León and Castile these contributions of Muslim scholars became known in western Europe and profoundly influenced the researches of Robert Grosseteste, Roger Bacon, Leonardo da Vinci, Johannes Kepler, and other scientists.

On the decline of the Roman Empire, and particularly after the closing of the schools of learning in Athens in the year A.D. 529 by the Emperor Justinian, the legacy of Greek science passed to the East, mainly owing to the efforts of the Nestorians in such centres as Antioch, Edessa, and Nisibis, and to a lesser extent through the waning Alexandrian School in Egypt. Nestorians were particularly well received at the Sāsānian capital of Jundīshāpūr in south-west Persia, and here arose a great centre of learning, where east and west mingled, and where the Greek rationalist outlook on the universe held its own against oriental mysticism until the triumph of Islām. When, on the establishment of the 'Abbāsid caliphate in Baghdād, the leadership in culture passed to that city around A.D. 750, the scientists of Islām were able to build their knowledge upon both the geometrical methods of the Greeks and the analytical approach of the Hindus—though they generally favoured the former, which indeed proved ultimately to be a limitation, as it had been with the Greeks themselves.

The Arabic language was an admirable medium for the transference of the new thought, and during the period A.D. 750–900 the classics of Greek physics were sought out, translated with commendable industry, and sometimes improved upon. Moreover, algebraical and trigonometrical ideas were derived from the Sanskrit. During this time of translation, some of the physical works of Aristotle were made available by Hunain ibn Ishāq (809–877) and his many collaborators; Al-Kindī wrote an improved version of the *Optics* of Euclid; Thābit ibn Qurra studied the 'Roman' steelyard; and the Banū Mūsā (the three sons of Mūsā ibn Shākir) completed *c.* 860 *The Book of Artifices*, a treatise on mechanics. Indeed, it will be seen presently that the Arabic contribution to physics was mainly in optics and mechanics, particularly the former.

Arabic science reached its zenith between about A.D. 900 and 1100, and in this phase we encounter a galaxy of great intellects: men of wide learning, tolerance, and travel, who mastered all the knowledge of their day and reproduced it in their encyclopaedic writings. Among them were Ar-Rāzī (Rhazes), a celebrated physician, who also studied optics and the properties of matter and motion, space, and time; Ibn Sīnā (Avicenna), 980–1037, eminent as philosopher, physicist, and physician, who wrote a great work on physics, a beautiful copy of which was obtained by Sir Francis Younghusband from the oasis of Yarkand and is now with the Royal Asiatic Society; Ibn al-Haitham (965–1039), one of the greatest optical students of all time; and Al-Bīrūnī ('The Master') —973–1048—a contemporary of Firdausī at the Court of Maḥmūd of Ghazna. Al-Bīrūnī was a many-sided genius, whose work in several branches of learning remains classic, and who made in particular a careful study of the specific gravities of metals and precious stones.

We select Ibn al-Haitham, known in medieval Europe as Alhazen, for particular note. Born at Basra, he spent the last years of his life in the vicinity of Al-Azhār in Cairo. His greatest work is the *Optics* (*Kitāb al-manāzir*), a Latin version of which appeared in 1572 [1]. Until lately the Arabic original was believed lost, but a manuscript has been found in Istanbul and is the basis of some recent researches by Mustafā Nazīf Bey [2]. Al-Haitham not only improved upon the knowledge of optical reflection inherited from the Greeks, but was the first to make an elaborate investigation of refraction. By competent mathematical investigation he extended the laws of reflection, which had been considered mainly by Euclid and other Greek thinkers in relation to plane mirrors, to the case of concave and parabolic mirrors [3], and he undertook the actual construction of steel reflectors by means of a kind of



كان الفصل المشترك بينه وبين السطح المقعر هو خط ا ج و. وقد كان الفصل
المشترك بين السطح الذي انطبق عليه وصار معه سطحا واحدا وبين السطح
المقعر هو خط ا ح ه فخط ا ب ج ينطبق علي خط ا ح ه ويصيران
خطا واحدا ويصير للسطح كله مساويا للسطح فخط ا ح ه
هو قطع مكافي مساو لقطع ا ب د وسهمه ا د وذلك
ما اردنا ان نبين ه
اكل سطح مقعر تقعير المجسم المكافي يفصل من طرف سهمه
مثل ربع الضلع القائم للقطع الذي احدثه فان كل خط يخرج موازيا للسهم وينتهي
الي السطح المقعر وينعطف الي تلك النقطة فانه يحيط مع الخط المماس للسطح المقعر

الي جميع بسيط السطح المرائي علي خطوط متوازية للسهم فاقول ان جميعها
ينعكس الي نقطة ح ولان سطح ا ه ب سطح مقعر تقعير المجسم المكافي
يكون جميع الخطوط الموازية لسهمه اذا انتهت اليه وانعكست الي نقطة ح
احاطت مع الخطوط المستقيمة التي تخرج في سطوحها مماسة للسطح المقعر بزوايا

خطا ط ب ب ح يحيطان مع خط ك ب ل بزاويتين متساويتين كما بين
فيما تقدم فخطا ط ب ب ح يحيطان مع الخط المماس للسطح المقعر الذي هو
الفصل المشترك بين سطحي خطي ط ب ب ح وبين السطح
المماس للسطح المقعر بزاويتين متساويتين وكذلك تبين
ان كل خط يخرج موازيا للسهم وينتهي الي السطح المقعر
وينعكس الي نقطة ح يكون هذه حاله وذلك ما اردنا
ان نبين ه كل سطح مراة مقعر تقعير المجسم المكافي
تقابل به جرم الشمس حتي يكون سهمه مسامتا لجرمها فانه يخرج من جرم الشمس
الي جميع بسيطه شعاعات ينعكس كلها الي نقطة واحدة علي سهمه ويكون بعدها

Parts of a MS. of the work of Ibn al-Haitham. The centre figure shows parallel rays from the sun striking a parabolic mirror.

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lathe. In this way he was able to discover spherical aberration (though he failed to consider the caustic curve), and, on the basis of the conics of Apollonius, to establish an exact focus in the case of the paraboloid. This happy combination of analysis and synthesis places Al-Haitham among the great scientists. His methods influenced not only some of his successors in the east, but also Robert Grosseteste, John Peckham, Roger Bacon, Witelo, Leonardo da Vinci, and Johannes Kepler in the west. The application of rigid mathematical methods to physical problems enabled Al-Haitham to determine the point of reflection on a concave spherical mirror when the positions of the object and the eye are known; the resulting equation of the fourth degree was solved by the intersection of a circle and a hyperbola. The elaboration of such work, involving cubic equations, from the initial treatises of Archimedes and Apollonius, was a unique Arabic achievement, leading to a solution of certain physical problems and to the greatest algebraical treatise of medieval times, the *Algebra* of 'Umar Khayyām. The first use of the camera obscura is ascribed to Al-Haitham; he also made a study of the onset of twilight [4], in which he gives 19° as the angle of depression of the sun below the horizon for its occurrence; and he gave the luminous object as the source of light, as did Ibn-Sīnā and Al-Bīrūnī, in contradistinction from Euclid and Ptolemy, who had believed that the rays originated from the eye.

The new departure made by Al-Haitham lay, however, in the subject of refraction. A remarkable experimental investigation of refraction had been made in antiquity and is generally attributed to Ptolemy, but Al-Haitham's work reads in places like a seventeenth-century treatise. He related the change in direction of a ray of light on entering a medium of different density to an alteration in the velocity of the light, the light travelling more slowly in the denser medium; there were two properties, transparency and density, the former facilitating motion, the latter retarding it. By imagining the velocity of the incident ray to be the resultant of two components, one in the direction of the normal to the surface of separation of the two media and the other parallel to that surface, he was able, by reducing the latter velocity, to account for a position of the refracted ray nearer to the normal when the second medium is the denser, and, conversely, for a movement of the ray away from the normal when the second medium is the rarer. It is interesting to note that while Al-Haitham's interpretation accorded with experimental fact, Sir Isaac Newton's theory, of some seven hundred years later, did not; for Newton, assuming that light consists of corpuscles endowed with great velocity,[1] increased the normal component of this velocity so that the resultant value became greater in the denser medium. Newton's investigations into the nature of light, however, were more profound, for Al-Haitham hardly went beyond the fact of a very great velocity. There are, nevertheless, five outstanding features in Al-Haitham's work: firstly, he was clearly aware of the principle of inertia, later stated as Newton's First Law of Motion, in his conception of the path of a ray of light; secondly, his handling of the mechanism of refraction reveals a competent knowledge of the rectangle of forces, though he does not seem to have considered the possibility of altering the normal component of the velocity as Newton did; thirdly, his statement that a ray of light takes the path, through a medium, which is the 'easier and quicker,' brings him near to Fermat's principle of least time; fourthly, he knew the first law of refraction, that the incident and refracted rays and the normal to the surface of separation lie in the same plane; and finally, though he failed to discover the second law, which Snell found in 1621, his experimental results indicate that he handled apparatus competently and fully realized the necessity of the empirical approach to knowledge. It is a pity that Al-Haitham did not perceive the sine relationship. The Greek method of reckoning by chords, and the sine of an angle (*jyā*) as used in the Hindu Siddhāntas, had already become known to the Muslim scientists; in particular, Al-Battānī, of Sabian origin, who died in A.D. 929, had already extended trigonometry to spherical triangles. Al-Haitham also investigated the magnification produced by a lens, and the phenomenon of atmospheric refraction.

In the year 1258 Naṣīr ad-Dīn aṭ-Ṭūsī[2] was appointed chief astronomer, and an observatory was erected, at Marāghah in Adharbaijān, on the order of the Mongol, Hulāgū Khān. With the aid of assistants gathered from Damascus, Mauṣil, Tiflīs, and Kazvīn, Aṭ-Ṭūsī made beautiful astronomical instruments of exquisite workmanship, and completed, under Abaqā Khān, the famous Ilkhānian astronomical tables. Aṭ-Ṭūsī, as one might expect, was also interested in optics, and wrote about reflection, making a version of the *Optics* of Euclid as Al-Kindī had done earlier, but he seems to have failed to understand refraction; he was primarily a geometrician in outlook and was restricted by Euclidean methods. One of his pupils, Quṭb ad-Dīn ash-Shīrāzī (1236–1311) did, however, study the refraction of light in the raindrop, and was instrumental in calling the attention of his own pupil, Kamāl ad-Dīn al-Fārisī (died *c.* 1320), to the *Kitāb al-Manāzir* of Al-Haitham, Book VII of which, on refraction, had apparently been ignored. Al-Fārisī, in the early fourteenth century, made an abridgment from an autograph copy of Al-Haitham, and then wrote a valuable commentary with his own observations, entitled *Tanqīḥ al-Manāzir*.

Questions on optical refraction had engaged the attention of Muslim scholars in the first half of the thirteenth century, owing to the enthusiasm and broad outlook of Frederick II of Sicily, who linked Islām with Latin Christendom. His influence lasted, long after his burial in Palermo in 1250, well into the fourteenth and fifteenth centuries. He was—with Raymond I, Archbishop of Toledo, in the twelfth century, and Alfonso X of León and Castile in the late thirteenth century—one of the agents who inspired the translation of Arabic treatises, some on physics, into Latin. In correspondence with scholars in the Muslim world Frederick II posed questions such as: Why do oars immersed in water appear bent? Why does Canopus appear larger when near the horizon, even when the atmosphere contains no moisture? Frederick's foundation of the university of Naples in 1224, with its collection of Arabic manuscripts, and his transmission of translations to Bologna and Paris, were instrumental in bringing the latest Muslim ideas into Europe; no doubt the optical theories of Witelo and Roger Bacon owe something to the university of Paris.

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[1] Ibn Sīnā had also used this hypothesis.

[2] Naṣīr ad-Dīn (1201–74) of Ṭus in Khurāsān. Many of the 'Arabic' scientists were actually Persians: we use the term Arabic rather than Arab.

By 1150 Arabic science was generally in decline. There did come to fruition, however, the line of development initiated in the ninth century A.D. by the Banū Mūsā, namely the Muslim application of Hellenistic mechanics. There was not much originality in theory, but there were ingenious and beautiful contrivances based upon the *Mechanics* of Hero of Alexandria and the *Pneumatics* of Philo of Byzantium. Great attention was paid to the determination of specific gravities, using the principle of Archimedes; to problems arising out of the use of the lever and balance; to clepsydras or water-clocks; to water-wheels; to fountains; and to various other automata. As early as 807, an elaborate water-clock had been presented to Charlemagne by the Caliph Hārūn ar-Rashīd. About the middle of the twelfth century, a clock was installed in the Bāb Jairūn at Damascus, and this clock became famous; Ibn as-Sāʿātī wrote a book about it in 1203. Just after the beginning of the thirteenth century there were written the two chief Arabic works on mechanics, namely the *Kitāb mīzān al-ḥikma* of Al-Khāzinī of Merv, and the *Kitāb fī maʿrifat al-ḥiyal al-handasīya* (*c.* A.D. 1205) of Al-Jazarī. The former dealt with the measurement of time, with the theory of the lever (continuing the work of Thābit ibn Qurra), with capillarity, and with gravity, which was supposed to be directed towards the centre of the universe and to affect the sea and the atmosphere; it gave also tables of specific gravities of liquids and solids. Al-Jazarī was more technological, treating mainly of clepsydras, fountains, and other contrivances operating on hydraulic principles. The glorious achievement of the ʿAbbāsid caliphs such as Al-Ma'mūn (813–833) at Baghdād was emulated in the following century by the Umayyad dynasty in Spain, notably by Al-Ḥakam at Córdoba (961–976). Córdoba was 'the Jewel of the World' in the tenth century, the cultural focus of Europe, where one could walk for ten miles in a straight line by the light of the public lamps. Spanish Muslims, in particular Al-Zarqālī (*c.* 1029–87), made fine scientific instruments, including astrolabes. The astrolabe occupies a key position in medieval astronomy, and although a discussion of its merits is outside the scope of this article, it is indicative of the skill attained by the Muslim instrument makers, who were frequently physicists and astronomers as well. This skill was still being exercised in the observatory of Ulūgh Beg at Samarkand in 1437.

Outside optics and mechanics the medieval world achieved little in physics, the other branches of the subject not having been freed from various metaphysical speculations or generally reduced to mathematical expression. Jābir ibn Ḥayyān commented in the eighth or ninth century on the nature of magnetic force; and though the derivation of the magnetic compass may be Chinese, it was first widely used for navigational purposes by Muslims in medieval times, and is mentioned by Alexander Neckam, who died in 1217. Apart from the outstanding researches of Ibn al-Haitham, the general temper of physics was Aristotelian, as we find it in many of the Arabic encyclopaedic and philosophical works, such as those of Al-Kindī, Al-Fārābī, Ibn Rushd (Averroës), and Ibn Sīnā, and of the Brethren of Sincerity (Ikhwān aṣ-Ṣafā'). Aristotle's *Meteorologica* led to a 'meteorology' of wide generality, embracing what we should now define as meteorology together with perspective, which latter involved both physical and physiological optics. Large-scale natural phenomena, such as the tides, commanded attention, and many successful measurements were made in physical geography. The theory of the rainbow, especially, figures throughout Arabic physics from Al-Kindī to Ash-Shīrāzī, initially in terms of reflection on the basis of Aristotelian and Euclidean ideas, and finally incorporating the theory of refraction which derived from Ibn al-Haitham. Musical intervals were studied by Ibn Sīnā, who wrote about them in his *Kitāb ash-Shifā'*.

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Heredity in pneumococci

HARRIETT EPHRUSSI-TAYLOR

The direct control of heredity, as opposed to selective breeding to maintain races in which desired characteristics are always present, has been one of the main goals of the practical geneticist. The discovery that a specific agent—a highly polymerized desoxyribonucleic acid—can transform one strain of pneumococcus into another with different serological characteristics is, therefore, most significant. This article discusses how far the discovery can be regarded as an example of direct control of hereditary character, and explains why it should not be taken as an instance of an effect of environment on genetic make-up.

Everyday experience demonstrates that hereditary mechanisms are conservative. Offspring tend to resemble parents very closely, and it is the gross deviation from this occurrence that surprises us. This is fortunate, for, were the hereditary constitutions of individuals readily affected by environmental factors, the perpetuation of species would be gravely endangered. In spite of this conservatism, gradual evolution of species continually takes place. To understand how both conservation and gradual evolution of species occur is one of the great problems of modern biology. Even more challenging is the problem of gaining control of heredity, to guide the evolution of species to the ends which man considers good.

The science of genetics has set out to explain the mechanisms of heredity and its variation. Geneticists now understand fairly well how the characteristics of diverse species of plants and animals are conserved. Oddly enough, the research which has culminated in the formulation of the laws and theories of modern genetics did not develop through the study of the constancy of species-characteristics so much as through the study of rare mutations in these characters. These mutations, often consisting of hereditary malformations, provided essential markers for the genetic material in individual organisms, and thus enabled the geneticist to study how this genetic material is passed on to offspring. Just as mutations have been of primary importance in the study of heredity in higher plants and animals, so they are now playing an important role in the development of the genetics of bacteria. The present article deals with a remarkable kind of mutation in bacteria, that of specifically induced transformations in *Pneumococci*. However, before turning to examine this phenomenon, let us touch first upon some of the essential points of modern theories of heredity.

In probably all cells there are to be found special structures which cannot arise *de novo*, and which are exactly "copied" during cell-multiplication to form the hereditary substratum of the new cell. If any part of these structures is lost, the cell cannot by itself replace it, for it is only when these elements are themselves present that their reproduction can take place. In addition to being responsible for their own reproduction, these elements initiate reactions which lead to the formation of structures and performance of functions. The hereditary substratum is composed of units which can be differentiated both by their specific physiological activities and by their localization in cell-structures. These units, called genes, have the dimensions of large molecules, and probably differ structurally from each other at the molecular level. While one can already see in these hereditary units the makings of a system which is conservative in function, its stability would not exist without mechanisms to assure each newly produced cell a complete set of genes. Such a mechanism is known to exist in higher plants and animals, where genes are aligned in long structures called chromosomes. The number of these thread-like structures, and their size, differ for each species, and are species-characteristics. Before cell division, the genetic material in the chromosomes is duplicated, and the chromosomes split longitudinally, so that each new thread contains at least one copy of each gene. During cell-division, each daughter cell receives one of the two threads formed from each chromosome of the reproducing cell.

The greatest genetic variability is found in organisms which reproduce sexually. This is so because in the course of sexual reproduction only one-half of the chromosomal material of each parent is utilized to form the fertilized egg. Thus the new individual draws upon two different individuals for its genetic material, and is composed of only a part of the genetic patrimony of each partner. Since the new organism is not the simple sum of the total genetic material of each parent, and represents an assortment of only half of this material, new combinations of hereditary characters arise with each individual produced by a given pair of parents. At present, man cannot control which parts of the genetic material of sexually reproducing organisms will be passed on to their descendants. However, by following scientific breeding procedures, he can increase the incidence of desired properties in the offspring, or even produce true-breeding races in which the desired character is always present as long as matings are made according to strict rules.

While heredity as a whole operates to conserve the forms and functions of organisms within certain limits, new characteristics do appear from time to time. In the reproduction of every hereditary unit, or gene, there is a certain probability that the copying process will not be carried out exactly, and that a gene having new properties will appear. The probability is very small, and can be estimated only with difficulty. This spontaneous mutation of hereditary units provides a source of new kinds of hereditary material.

Since man cannot predetermine which genes are to be passed on to the offspring of sexually reproducing organisms, it has been stated that he has no control over heredity. The validity of this statement depends, of course, on what one means by control. It has been possible to create lines of plants and animals which breed true for certain desired characteristics, and it is thus clear that the hereditary substance of organisms can be manipulated for the purposes of mankind. However, one may have a very different kind of control in mind, and, indeed, this kind of control has been dreamed of by geneticists for many years. From various lines of biological research it seems likely that genes perform very specific operations in the organism. One can imagine that some day we shall be able to alter the gene specifically, to make it perform certain new desired functions. At present, there is no evidence that such control has ever been achieved. It has been possible by the use of X-rays and various other agents to increase —in a random fashion—the incidence of mutations, and this in turn has given a new degree of control over heredity. It has permitted man to increase the natural reservoir of variability inherent in genetic systems, thereby providing more new genes from which to select desirable ones. It falls short, however, of the imagined goal.

It is upon a background woven out of the efforts of geneticists to gain control over genetic systems that we should examine the nature of a rather recent discovery, viz. the transformation of pneumococcal types. At first sight, this phenomenon appears to offer the possibility of controlling the hereditary properties of an organism. It is proposed, consequently, to examine the essential aspects of the phenomenon, and then to discuss to what extent we are justified in supposing that we have at last attained the direct control of a hereditary character.

Virulent pneumococci synthesize polysaccharide capsules about themselves, which permit them to grow in their animal hosts unsuppressed by phagocytic destruction. The ability to synthesize a capsule is a constant hereditary trait. In nature, different races of pneumococci can be found, which differ from each other with respect to the chemical structure of the polysaccharide composing their capsules. The formation of a capsule of a given chemical structure is, again, constant in a given line, and therefore a hereditary trait. Distinctive kinds of antibody are formed against each type of capsular polysaccharide when the encapsulated bacteria are injected into animals. Consequently, by serological means, pneumococcal strains can be classified into groups. In a given group all races form the same kind of capsular polysaccharide, although the individual strains may differ with respect to other characters. The grouping or "typing" of pneumococci is arbitrary, but is based upon a very exact criterion.

From time to time mutation occurs in the capsule-forming mechanism, and there appear pneumococci which have a diminished power of capsule synthesis, or even a total loss of this capacity. From such mutants one may establish lines in which capsule synthesis is permanently diminished, or lines in which capsules are totally lacking. The mutated states are thus hereditary.

In 1928, Griffith discovered that unencapsulated pneumococci could be made to form capsules again, if they were injected into mice simultaneously with heat-killed encapsulated pneumococci. This discovery was particularly remarkable, since it was evident from Griffith's experiments that the induced capsule was identical with that formed by the heat-killed bacteria, and independent of the origin of the unencapsulated pneumococci in which the induction had occurred. Thus, an unencapsulated bacterium which had been derived from a Type II encapsulated race could be made to synthesize the capsule of a

Type III race, provided the induction was done in the presence of heat-killed Type III bacteria. From this basic observation the phenomenon has received its name of 'transformation of pneumococcal types.'

It seemed likely that this transformation was due to the presence of a specific agent in encapsulated bacteria. Study of the phenomenon was taken up in the laboratory of Avery, where it was found that the induction could be done with cell-free extracts of encapsulated pneumococci, acting *in vitro* upon cultures of unencapsulated pneumococci growing in a special medium. After eleven years of study of the inducing agent, Avery and his co-workers MacLeod and McCarty published the results of their research upon its chemical nature (1944). All chemical and biochemical evidence indicated that the transforming agent (TP) was probably a highly polymerized desoxyribonucleic acid. The publication of this result has roused much comment from both geneticists and chemists. From Griffith's experiments, geneticists had become interested in the transformation phenomenon, since it seemed that for the first time man was inducing a specific inheritable change in an organism. That the inducing substance should be a nucleic acid of the desoxyribose type excited still greater interest, for this is a substance which in higher plants and animals is known to occur only in the chromosomes. For many years, geneticists have speculated about the chemical nature of genes, and because proteins were known to have special structures and biological activities, it was supposed that the protein parts of the chromosomes were differentiated to give rise to gene-specificity. Before the studies on the pneumococcal TP were published, there had been no reason to believe that nucleic acid molecules in the chromosomes had a role in determining the specific properties of each gene. Chemists and biochemists were similarly interested by the studies on the TP of pneumococcus, since it had been supposed, on the basis of admittedly limited chemical evidence, that the desoxyribonucleates isolated from such different sources as wheat germ and calf thymus were chemically identical. If the transforming activity of the desoxyribonucleic acid extracts of encapsulated pneumococci is due entirely to their content of this substance, it follows necessarily that nucleic acids of the desoxyribose type must have diverse biological specificities, and hence must also have diverse chemical structures. This is evident from the experiments of McCarty and Avery (1946*a*), who isolated in purified form the desoxyribonucleates of three different types of encapsulated pneumococci. Each preparation induced unencapsulated pneumococci to form capsules, but each transformed the bacteria into a different type. The type of polysaccharide found in the induced capsule depended always upon the source of the transforming extract. Thus the kind of new synthetic activity acquired by the transformed bacteria was determined by the origin of the nucleic acid with which the induction was accomplished. It should be noted also that desoxyribonucleic acid of calf thymus is totally inactive as an inducing agent.

It is difficult to be certain that no other material in the desoxyribonucleic acid extracts contributes to their specific activity, for these extracts are active in trace amounts. However, extensive serological, chemical, and biochemical studies carried out by McCarty and Avery (1946), and by Hotchkiss (1948), indicate that no complex organic sustance other than desoxyribonucleic acid is detectable in these extracts. Furthermore, biological activity is destroyed by any agent which depolymerizes the nucleic acid. Thus, transforming activity is rapidly destroyed by crystalline desoxyribonuclease, a specific depolymerase, but is untouched by proteolytic enzymes or ribonuclease. Apparently, therefore, the polymerized desoxyribonucleic acid is solely responsible for the biological activity of the pneumococcal extracts.

As a biological agent, the capsular TP of pneumococcus presents some interesting features, since it has a dual action in the transformed bacterium. It induces both capsule formation and its own reproduction by the bacterium. Thus, once transformed, the bacterium passes a copy of the TP on to its progeny, and they, too, form capsules. The TP therefore possesses properties attributed to genes, in that genes also have this same dual role. We may, therefore, suppose that the capsular TP is simply a part of the genetic substratum of the encapsulated pneumococcus, which has been extracted in active form and introduced into the unencapsulated bacterium. Were this the case, we should expect to find other resemblances between the capsular TP and genes, and, as well, other gene-like agents in the desoxyribonucleic acid extracts.

Inside the bacterium, the capsular TP undergoes spontaneous mutations upon very rare occasions, much as genes do (MacLeod and Kraus, 1947; Taylor, 1949). These mutations give rise

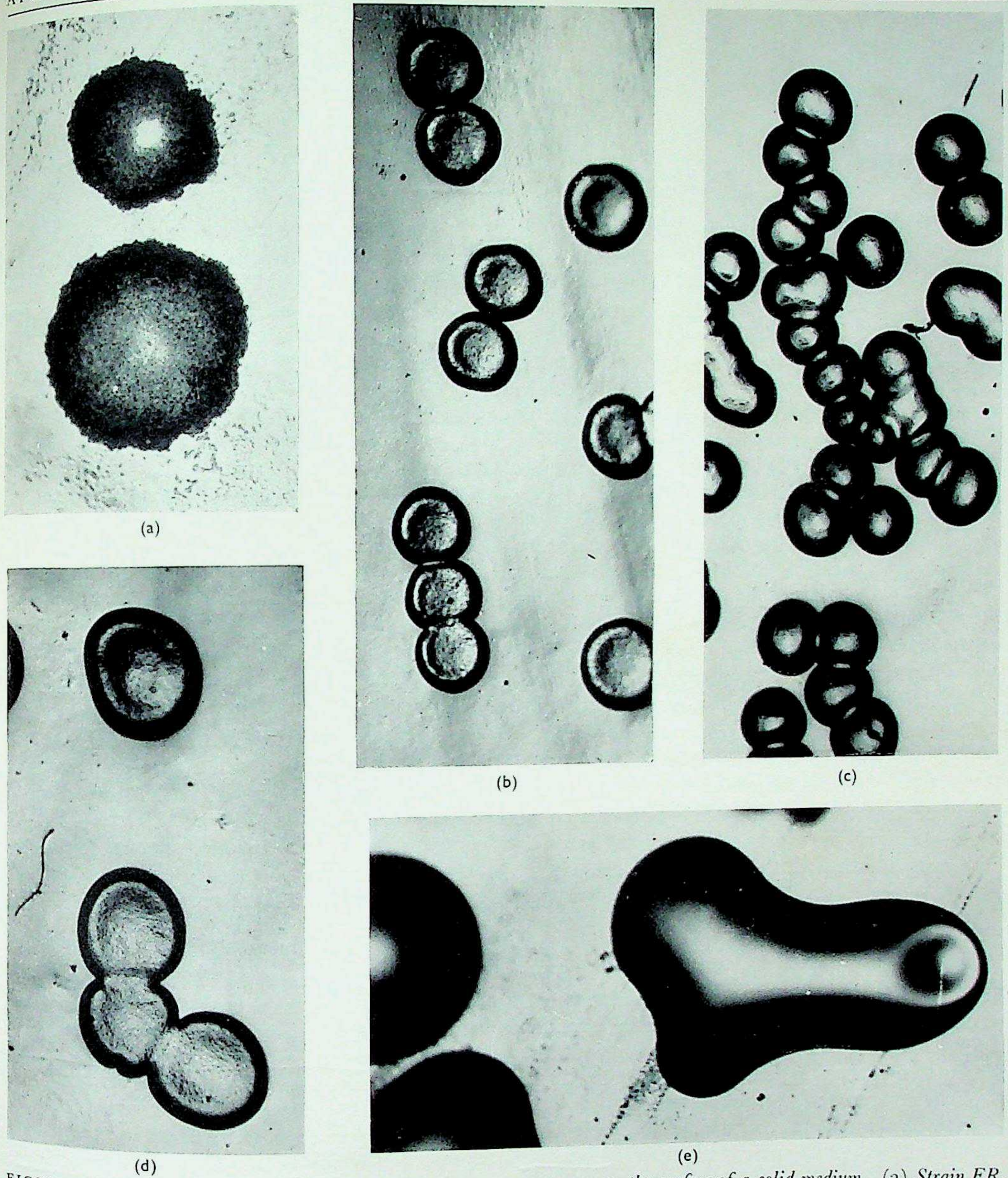

FIGURE 1 – *Photographs of colonies of strains of* Pneumococcus *grown on the surface of a solid medium.* (a) *Strain ER, an extremely rough colony. The bacteria are not encapsulated, and form long chains which become matted.* (b) *Strain R, rough colony. These also are unencapsulated, but do not form long chains.* (c) *Strain SIII–1, intermediate between rough and smooth. These bacteria form small amounts of Type III capsular polysaccharide. Reduced capsule formation is due to mutation of the capsular transforming agent.* (d) *Strain SIII–2, smooth colony. These bacteria are encapsulated, but also form less polysaccharide than does the normal SIII–N strain, owing to mutation of the capsular transforming agent in this race.* (e) *Strain SIII–N, smooth colony. Encapsulated with Type III polysaccharide.* (× 25)

to capsular transforming agents having modified biological activities (see figure 1). The mutated agents can be introduced into unencapsulated pneumococci by the transformation technique, where they induce the formation of modified capsules (see figure 2). The transformed pneumococci

Heredity in pneumococci

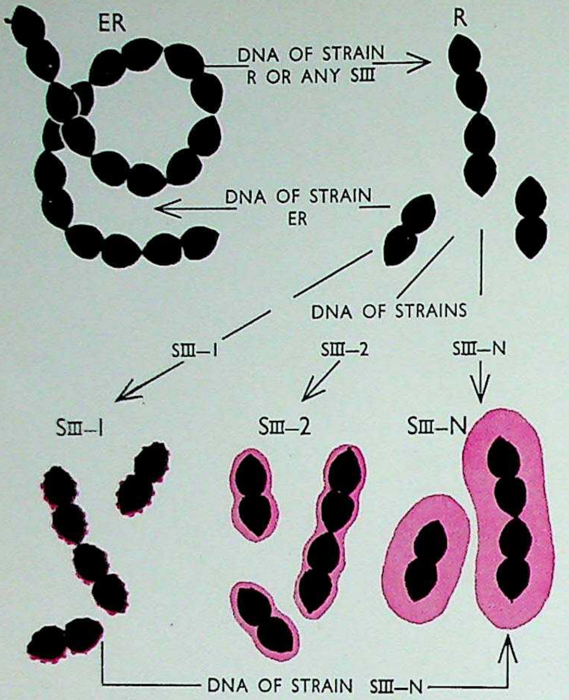

FIGURE 2 – *Diagram of some of the transformations which can be induced in the strains shown in figure* 1. *DNA = desoxyribonucleic acid fraction of the indicated strain. Red = Type III capsular polysaccharide. Note that the DNA fractions of the SIII strains have two different specific transforming activities: ER to R, and R to the SIII condition which corresponds to the source of DNA.*

copy the mutated agent faithfully and pass copies on to their progeny, just as occurs in the transformations with an unmutated capsular TP.

It has been found also that a given desoxyribonucleic acid extract has more than one kind of transforming activity. The desoxyribonucleate of Type III pneumococci, for example, contains at least two known kinds of transforming agents. One induces capsular polysaccharide formation in unencapsulated strains, and a second induces a distinctive morphological change in a particular strain of pneumococci (see figure 2).

In summary, it seems probable that the specific transforming agents are composed of desoxyribonucleic acids having different specific activities, and that they are parts of the genetic substrata of the bacteria from which they are isolated. In specific transformations, these agents become incorporated into the genetic constitution of the bacteria transformed, endowing them with both new genetic elements and new hereditary characters.

To what measure have these studies advanced our control of genetic systems? One should not conclude that we have finally acquired control over the biological properties of a genetic substance, for we have not yet influenced the properties of the gene-like transforming agents themselves, nor have we created a genetic element *de novo*. In pneumococcal transformations, a ready-made agent is taken from one bacterium and made to interact effectively with another, thereby endowing the transformed bacterium with new hereditary properties. Consequently, in one respect, these transformations resemble hybridizations, in that they are the manipulation of preformed genetic material. We may hope some day to be able to modify at will the properties of transforming agents, for these agents are easily accessible outside the cell and in solution in a test-tube. Perhaps, even, chemists will be able to explore the chemical structures of these agents sufficiently to permit the synthesis of gene-like agents from relatively simple organic molecules.

While there is every reason to believe that through a study of these transformations we shall gain much new insight into the structure and function of genetic determinants as a whole, there is, at present, no basis for supposing that the discovery of the transformation phenomenon represents a clean break with the concepts of modern genetics. Although these transformations are induced by agents which are introduced into the environment of growing bacteria, and can be called 'environmental agents,' the origin and properties of the transforming agents are such as to make one believe that we are concerned here with the introduction of new genetic material into the bacterium, and not with the modification by environmental factors of the hereditary substratum which the bacterium already possessed. The transforming agents which we isolate from various bacterial strains have their own unique properties, and for the moment their properties are as uncontrollable by man as those of the gene.

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Polled cattle

JOHN HAMMOND

All English children love the nursery-rhyme featuring 'the cow with the crumpled horn,' but the unreflective man or woman may think it unimportant whether or not cattle have horns. Dr Hammond describes the history of polled or hornless cattle—which goes back to ancient Egypt of 2150 B.C.—and explains that for several reasons polled cattle are desirable. Horned cattle may be dehorned, as calves, by chemical means, but, during the last few decades, methods of breeding polled cattle have been successfully studied and adopted.

So far as is known from fossil remains, all primitive breeds and species of cattle were horned, although this is doubted by Arenander, who cites *Leptobos frazeri* and some other hornless types of the Pleistocene period in India, which have been described by Rutmeyer. It is generally believed that polled breeds arose as mutations or sports from horned varieties. Characters such as horns are inherited by means of chemical substances called genes, arranged in pairs on the chromosomes of the nucleus of the animal cell. Genes determine the formation of the character in the new individual. When, by chance, the chemical nature of a gene is changed (as it can be sometimes by X-rays and other means) it gives rise to a mutation or sport. Most of these mutations are recessive in inheritance, that is, the character in question disappears in the first generation of a cross with the normal primitive variety, and then reappears in the next generation in the proportion of 1 in 4. The polled character in cattle is an exception in this respect, however, for although it is a mutation from the primitive form it behaves as a dominant, that is, one which appears in the first generation of a cross with the primitive type, and which, in the second generation, appears in the ratio of 3 to 1; two of these three will not breed true to polled, although the other one does (figure 4).

HISTORICAL

In general the history of cattle follows the history of man. Wherever either primitive or modern man has migrated, he has tended to bring with him his own breeds of cattle. An account of the literature on the origin of hornless cattle has been given by Dechambre (1922). In this he states that the earliest records of polled cattle in civilized countries occur in Egypt about the year 2150 B.C. (figure 1). Polled cattle were also described by Herodotus (*History*, Book IV) in southern Russia (Scythia). Whether these had the same origin and were transferred from Egypt is not known for certain. There exist in Africa today some native polled breeds of cattle (figure 2) kept by tribes in French West Africa, which no doubt have arisen from the Egyptian polled cattle, for, as Curson and Thornton (1936) have shown, there was probably a migration of tribes from the north to south of Africa along definite routes.

The next earliest account of polled cattle occurs in Scandinavia (figure 3), where, in Sweden, polled cattle of a small red breed (*Rod Kullig*) and also a white breed (*Fjäll*) existed, as they do to this day. It is possible that these were derived from southern Russia, for similar breeds also exist around Archangel in Russia, and it is known that tribes from southern Russia migrated to Finland. There is the possibility, however, in the lack of absolute proof of the transport of southern Russian polled cattle to Scandinavia, that the Scandinavian polled cattle arose from a local mutation, for it is a well-known fact that the same mutation may arise at different times and places. There is indeed recent evidence (see below) that the polled mutation has occurred independently during recent times among pedigree horned cattle in the U.S.A. and in Britain.

It is highly probable that the majority of such polled mutations in horned breeds would not survive under primitive conditions, for the polled character would be a distinct disadvantage in combat with other bulls of the breed, when they fought for their herds or in defence against predatory animals. Moreover, polled breeds would not be favoured and retained by peoples who use cattle for draught purposes, since in many lands the horns are frequently used to catch the cattle or to yoke them to the plough or cart. Conversely, the places where the polled mutation would be likely to be retained were those in which there was little cultivation, and cattle were required for meat and milk purposes only. Thus it was that

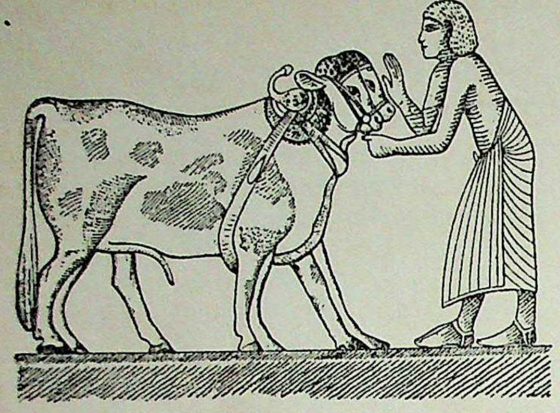


FIGURE 1 – *A polled bull of ancient Egypt* (*Kronacher*, 1921).

polled cattle obtained a strong footing in Scandinavia, while few records of the development of polled breeds exist in central and southern Europe, Asia, and most of Africa.

The primitive cattle of Great Britain and Ireland were all horned, and Wilson (1910) has described how the various polled breeds of British cattle were derived mainly from red stock brought over from Scandinavia by the Vikings. In Ireland, the Maol, a polled breed almost extinct today, was produced. In Scotland, the imported polled cattle breeding with the primitive black horned cattle of the Celts gave rise to the polled black Aberdeen Angus (figure 5) and Galloway, while Viking settlements in East Anglia developed the Red Poll (figure 6), possibly from pure Scandinavian stock and later by crosses of this with red horned breeds. Here also, by crossing with the white horned cattle introduced into Britain by the Romans, they gave rise to the polled Park Cattle which exist today in a few places. When men from Britain began to colonize North America, Australia, New Zealand, and South Africa they took many animals of these polled breeds with them, so that now polled cattle are distributed over both the south and the north temperate zones of the world.

In addition, however, to the polled breeds which were derived directly from Britain, polled strains of horned British breeds have arisen by mutations in North America, and have been developed there and elsewhere as separate breeds. Such polled mutations in normally horned breeds have arisen from time to time in Great Britain also, but hitherto they have not been preserved, since tradition and breed-society rules did not allow of the admittance of such animals to the herdbooks. Duerst (1931) gives references to cases of the polled mutation occurring in many different breeds of horned cattle. Within the last three years, polled mutations in pedigree Guernsey cattle (one in England and one in U.S.A.), and at least one in Jersey cattle (in England), have been recorded. It has been stated that the chances of this occurring are about once in 50,000 births (Clover, 1948). In the home of a long-established horned breed such mutations stood little chance of survival. It was otherwise, however, in new countries where the survival depended on the value of the new mutations to the stockbreeder rather than on the traditions of the breed. It was for this reason that when polled mutations occurred in the Hereford and Beef Shorthorn breeds in the U.S.A. in comparatively recent times they were retained and bred from. Nine polled sports were listed by Spillman (1907); two of these Hereford bulls came from horned parents and were used by Boyd in establishing a pure race of polled Herefords.

In 1901, W. Gammon of Des Moines, Iowa, circularized members of the American Hereford Cattle Breeders' Association, asking for hornless sports. 14 were found, and Gammon bought 7 cows and 4 bulls. The polled bulls mated with horned Hereford cows gave 50 to 75 per cent. hornless calves. A national breed organization for these polled Herefords was started about 1907 with a membership of 5, and by 1948 the new registrations of polled Herefords (figure 7), reached about 30,000 a year.

Owing to the demand for a polled beef animal which was a good grazer, these polled Herefords were introduced into Australia and are now spreading rapidly there. In the U.S.A., the polled Beef Shorthorn has also been developed. It is said to have originated in the State of Ohio about 1870 from pure-bred Shorthorn stock, and also in Minneapolis in about 1882, when a pedigree roan cow with scurs (small loose horns) produced three hornless calves. An American polled Shorthorn herdbook society was formed in Chicago in 1889, and the first herdbook was published in 1898. The polled Shorthorn is finding a ready demand in beef-producing areas, and has spread to the Argentine, Australia, and South Africa.

ARTIFICIAL DEHORNING

In beef breeds kept under range conditions, polled cattle are favoured, except where predatory animals exist, since animals suffering from injuries due to their horning one another are difficult to treat. Moreover, the presence of horns

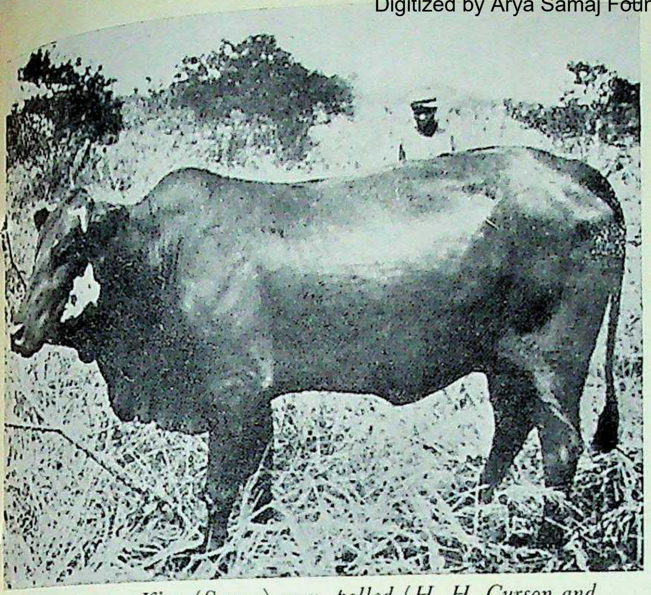


FIGURE 2 – *Kivu (Sanga) cow, polled (H. H. Curson and R. W. Thornton).*

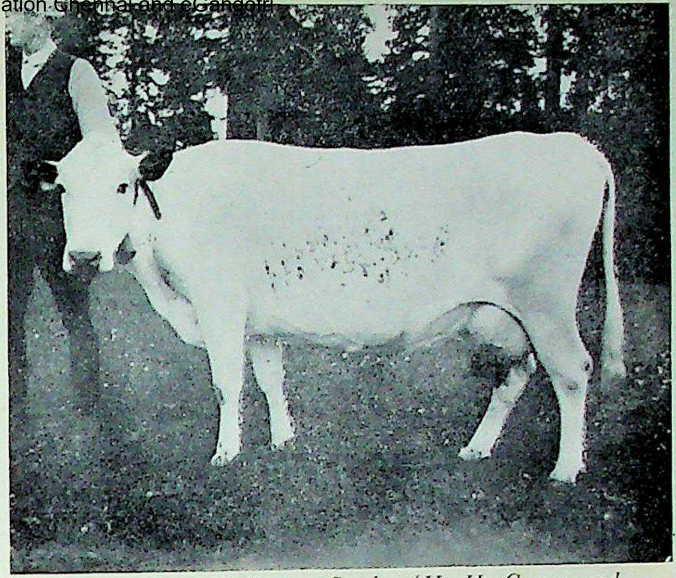


FIGURE 3 – *Fjäll cow, Sweden (H. H. Curson and R. W. Thornton).*

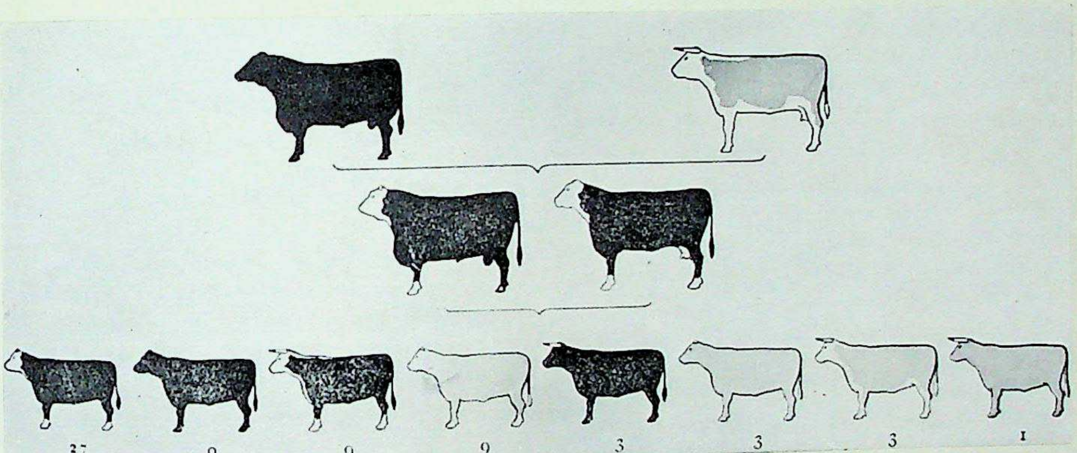


FIGURE 4 – *Diagram showing the character inheritance in cattle. The Aberdeen Angus has the black and polled characters which are dominant over the red and horned characters of the Hereford. The latter, on the other hand, has the white face pattern which is dominant over plain face. The three dominants appear in their progeny, but when these are interbred eight different types are possible, and the chances of each type appearing is indicated by the numbers beneath the animals.*

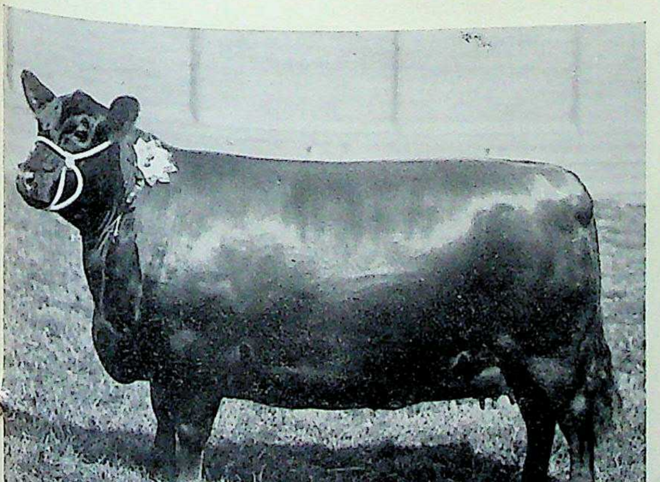


FIGURE 5 – *Aberdeen Angus cow* Julie Erica.

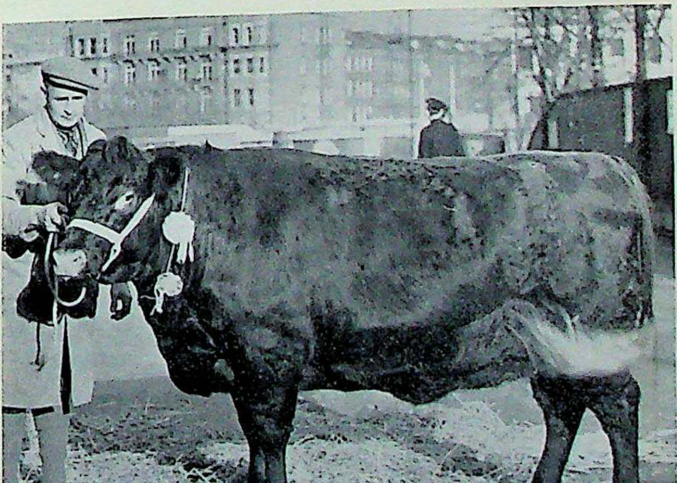


FIGURE 6 – *Red Poll heifer* Kirton Rueful Girl.

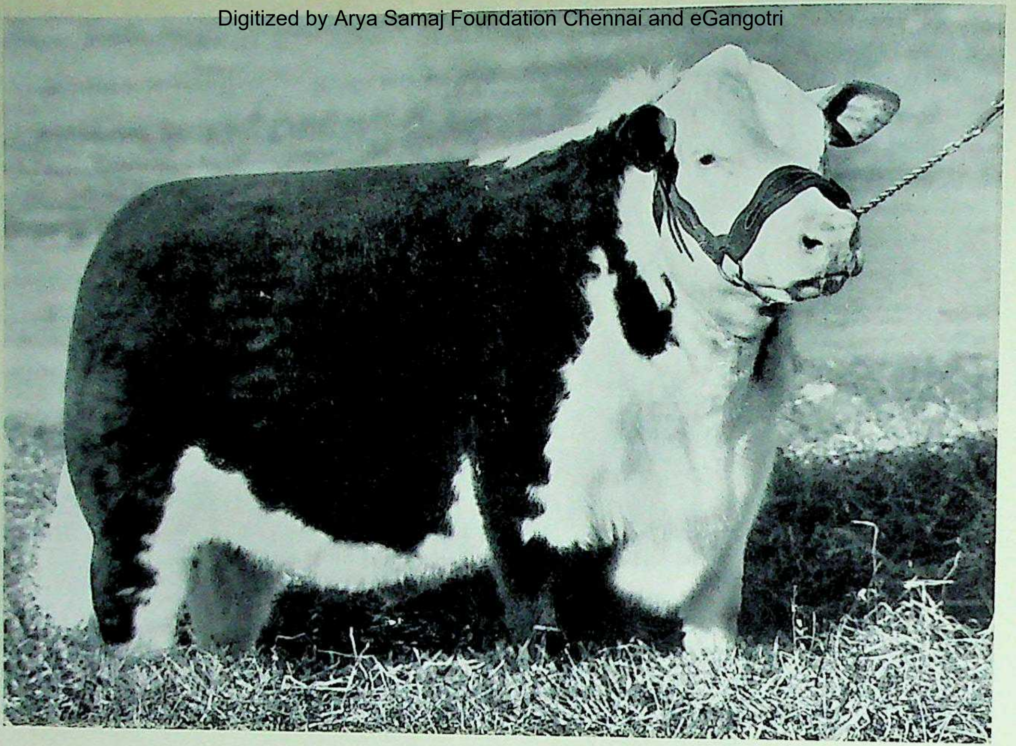


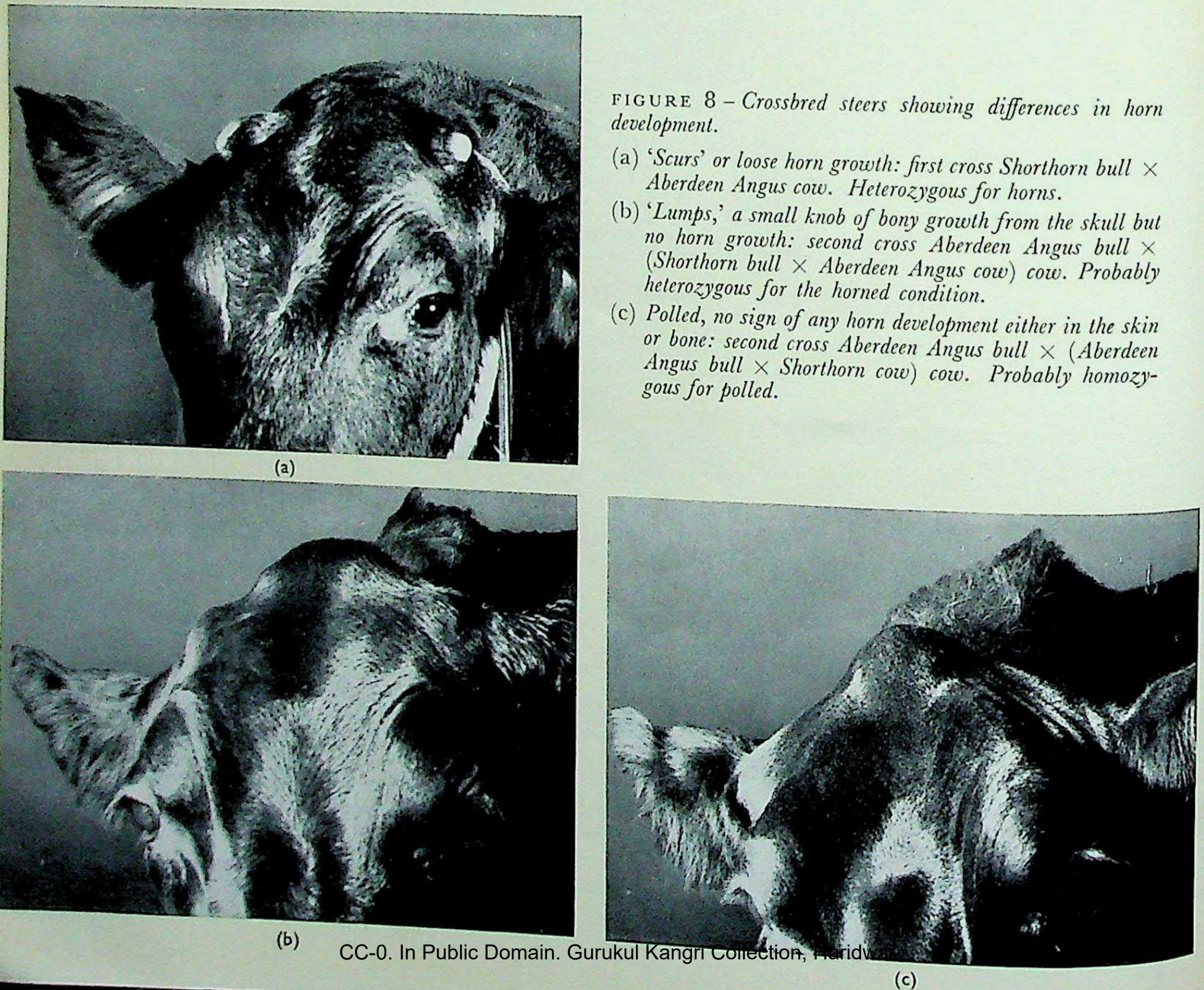
FIGURE 7 – *U.S.A. Polled Hereford Steer.*

FIGURE 8 – *Crossbred steers showing differences in horn development.*

(a) *'Scurs' or loose horn growth: first cross Shorthorn bull × Aberdeen Angus cow. Heterozygous for horns.*

(b) *'Lumps,' a small knob of bony growth from the skull but no horn growth: second cross Aberdeen Angus bull × (Shorthorn bull × Aberdeen Angus cow) cow. Probably heterozygous for the horned condition.*

(c) *Polled, no sign of any horn development either in the skin or bone: second cross Aberdeen Angus bull × (Aberdeen Angus bull × Shorthorn cow) cow. Probably homozygous for polled.*



(a)

(b)

(c)

is a frequent cause of bruises and spoilage in the carcass when the animals are rounded up to be put on rail to the abattoir, and more polled than horned cattle can be loaded in each rail wagon for transport. In most large beef-producing areas of the world (Argentine, Australia, New Zealand) the steers are therefore mostly polled or dehorned. This operation is best done by rubbing the horn core in the newly born calf with a stick of caustic potash. In extensive range areas, however, it requires a lot of labour to round up calves for this purpose, and under such conditions the young growing horns are often debudded with shears or sawn off, a rather cruel and bloody operation, at a later stage of life. No wonder, then, that polled breeds and strains are now extending in these areas. For intensive beef production under yard feeding conditions too, such as in Scotland and eastern England, polled cattle are favoured, for, by polling, trough space requirements are reduced and more cattle can be put in each yard; thus Irish store cattle sent to be fattened in eastern England are now all dehorned, for they fetch about £1 per head more there than do horned cattle.

As to dairy cattle, the modern system in most countries of using run-through milking sheds has necessitated the dehorning of the dairy cows. Before milking, the herd is usually run in to a confined space, and here, as well as in the rush to the milking bale to get milked, horns may cause injuries not only to the skin of the cow but also to the udder. Moreover, a dig in the ribs from another cow when going to be milked is not conducive to that placid state of mind which is necessary for the easy discharge of milk to the machine or milker. In dairy cattle there has not been the same urge to produce polled breeds, however, as there has been with beef cattle, because the process of dehorning is much easier where the calves are confined and reared by hand. For this purpose the caustic potash method, and an electric dehorner which burns round the periphery of the horn bud in the newly born calf, are mostly used. This is carried out in most dairying areas of the world where milking machines are in common use, such as in the U.S.A., Canada, New Zealand, and Australia, and the 'new look' is not now discriminated against in many shows in the U.S.A., the champion cow in the 1947 Dairy Congress Show being without horns.

PRODUCING POLLED BREEDS

Since dehorning involves much time and trouble, and employs labour which could better be devoted to other purposes, there is much to be said for producing new polled types of the horned breeds of cattle. To be set against this are the abolition of the primitive beauty of gracefully spreading or upturned horns, and loss to the cowboy of a means of casting or lassoing his steers, and, in some cases, of a means of rapid identification of cattle where numbers are branded on the horns. However, if new polled breeds were produced the stockman could always have the option of which strains—polled or horned—would suit his purpose best.

If it were desired, there are two ways in which a polled strain of a horned breed could be produced. The first is that of preserving the polled mutations which appear from time to time among animals of the pure horned breed—the way in which the polled Hereford (figure 7) has been produced. This could be encouraged by opening a polled section of the herdbook concerned, in which these animals and their progeny (with due precautions—see below) were entered.

The second method is that of crossing with a polled breed and then upgrading the resulting progeny to the pure breed concerned, as in the grading-up schemes which exist in all open herdbooks. This is the method which has been successful in producing the new sex-linked strains of different breeds of poultry in recent years. The polled Suffolk sheep, too, has been produced from crosses between the polled Southdown and horned Norfolk breeds, and now breeds true to the polled character. Some of the ancestors of the present Red Poll breed of cattle, which now breeds true for the polled character, were horned.

Both these methods are being used to develop polled types. Using the first method, that of collecting mutations which occur from time to time in the pure breed, the various breed societies fall into a graded series reflecting the attitude of the majority of their members. At the one extreme, even artificially dehorned animals are debarred from being registered as pure (Shorthorn and Hereford Societies of Great Britain); in other societies artificial dehorning is permissible although naturally-polled animals are not permitted (Friesian Society of Great Britain); while in several other societies (U.S.A. Holstein-Friesian, Guernsey and Jersey Societies) naturally-polled animals are admitted to the herdbook without any special note being made of the fact, or a special mark is made against the names of polled entries (U.S.A. Shorthorn and Ayrshire Societies). At the other extreme, the polled animals are registered in a separate herdbook by a separate breed society which is concerned with breeding them true to this character (Polled Hereford Society of the U.S.A.).

Within some of those breed societies which at present prohibit the registration of polled mutations, a few members have broken away. They are attempting to produce polled types by cross-breeding with a suitable (similar commercial qualities and colour) polled breed and then grading-up back to the original breed; for, while the polled and horned characteristics are inherited as units without blending, the commercial qualities are inherited in a quantitative blending fashion. Thus, while in first crosses between the polled Red Poll and the horned Ayrshire all the offspring are polled, in general build and commercial qualities the first cross is intermediate between the two breeds. When these first-cross animals are back-crossed to the pure Ayrshire, the offspring have 75 per cent. of the build and commercial qualities of the Ayrshire, while 50 per cent. of them are horned and 50 per cent. are polled. If these polled animals are now mated back to the pure Ayrshire again, the offspring have 83½ per cent. of the build and commercial qualities of the Ayrshire type, and 50 per cent. of them are polled, and so on for each successive generation of grading-up (see table).

Generation	*Per cent. Polled*	*Per cent. Commercial Qualities and Build of Ayrshire*
1. First cross ..	100	50
2. Polled offspring mated to Ayrshire	50	75
3. *Ditto*	50	87½
4. *Ditto*	50	93¾
5. *Ditto*	50	97⅞

Since all our dairy breeds of cattle now have an open herdbook and allow grading-up, all that would be necessary to obtain polled types of breeds would be to admit polled animals as foundation cows—the rest would then follow automatically with the grading-up.

When a high percentage of the pure breed characters is present in the grades (when the animals would be admitted as pure-bred) the next problem arises, namely that of getting them to breed true for the polled character. This is done by mating bulls and cows of the polled grades together, when 1 in 3 of the polled offspring will breed true to this character. To obtain true breeding it is quickest and most economical to concentrate on the bull, and pick out the 1 in 3 of the polled bulls which will breed true. Some indication of whether they are likely to breed true or not can be found (in the bulls, but not in the cows) by the absence of scurs or knobs (lumps of bone on the skull in the position of the horns), as bulls which are heterozygous for horned (or not breeding true for polled) will have these (see figure 8). After selection of the bulls has been made on this basis, it is advisable to make quite certain by doing a progeny test on the bulls before they are used for pure breeding. The young bull is mated with some 5 to 10 horned cows, and if without exception all the offspring are polled then the bull will breed true, but if even only one horned calf is found among the offspring then the bull should be rejected for further pure breeding. By grading-up the polled cows with such progeny-tested bulls the chances of horned offspring appearing in the breed will be reduced to zero, and they will become true breeding for polled in the course of time.

The chances of any of the polled cows in the herd ever breeding any horned offspring (even when mated with a horned bull) is reduced in each generation bred in this way from a succession of proven bulls: thus only 1 out of 3 cows will throw horned offspring to a horned bull in the first generation, 1 out of 6 in the second generation, and 1 out of 12 in the third generation, and so on. Using our knowledge of the Mendelian laws of inheritance it should be possible to produce pure polled strains of any breed of cattle without losing the characteristics of the breed in question, if it is so wished.

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Earthquakes

ERNEST TILLOTSON

Movements of the earth's crust provide information not merely for the seismologist but for geologists, engineers, and prospectors. In recent years some microseisms, caused by general unrest of the ground, have been found to be caused by storms at sea, and their study has proved useful for weather-forecasting. Here, earthquake phenomena are discussed with special reference to the New Zealand earthquake of 1929 and the Mikawa earthquake of 1945.

Deep rumblings and minor earth tremors are by no means uncommon in the town of Murchison and in the Buller River Valley in the north-west part of the South Island of New Zealand. Nobody takes much notice of them. But on 17th June, 1929, Murchison was wrecked by a violent earthquake [1]. In many places, the hills and the surrounding fertile flats were stripped to the bare rock, and great fissures were formed. The river Matakitaki ceased to flow below a newly formed lake which accumulated behind a dam of earth, rock, and *débris* piled up by the earthquake. Dams also appeared, with lakes behind them, across the Matiri, Maruia, and Buller rivers. Landslides made many roads impassable. Seventeen people lost their lives. Had the area north of Murchison been densely peopled there is no doubt that there would have been a heavy loss of life.

Elastic waves initiated in the focal region of the earthquake travelled through the body of the earth, and were received on sensitive seismographs at observatories throughout the world. Figure 1 shows the seismogram obtained on the Milne-Shaw instrument at the Royal Observatory, Edinburgh. A study of such records indicates that the depth of focus (i.e. the initial point of rupture) was normal, probably 18 kilometres—though a rather deeper focus was at one time suggested [2]. The release of what appears to have been compressional energy, probably by faulting at this depth, caused movement in the surface faults.

During the later Tertiary period in geological history the region appears to have been dry land, which the great crustal deformation of the late Pliocene broke into blocks differentially elevated, tilted, warped, and rotated. The breaking of the rocks near White Creek, 7 miles west of Murchison, and the uplift of the country east of it by some 16 feet, together with an average movement of the ground east of the fault of 9·4 feet north, showed renewed relative movement of the block. Figures 3, 4, and 5 show the surface effects, and the above brief description of this important earthquake brings out some general features of earthquakes which will be considered in rather more detail and with other examples.

NON-INSTRUMENTAL EVIDENCE

The intensity of earthquake violence in any particular place can often be estimated by its effects. The correlation of these effects with a particular number depends upon the scale in use, and upon critical estimation by an experienced observer. The Rossi-Forel scale and the Davison scale had wide use, but these have largely been supplanted by the Modified Mercalli intensity scale of 1931; this is an adaptation to present-day conditions of Sieberg's Mercalli-Cancani scale. The M.M. scale of 1931 divides macroseismic phenomena into 12 degrees, from 'not felt' to 'damage total,' and in this scale there is an attempt to make the divisions equal and precise [3].

When the intensity at several places has been assessed, it is possible on a map to draw lines of equal intensity, called isoseismal lines, and thus to estimate the area of greatest intensity of the earthquake. This does not necessarily coincide with the epicentral area (i.e. the point on the earth's surface immediately above the focus) as determined by instrumental observations, on account of geological surface structure, though the two are not often far distant. Unconsolidated deposits show relatively greater macroseismic intensity than does firm, consolidated rock.

If the epicentre is at sea, some information can be obtained concerning it by timing the arrival of the seismic sea wave at various points in its path.

INSTRUMENTAL EVIDENCE

Seismographs are instruments designed to record the passage of elastic earth waves. The

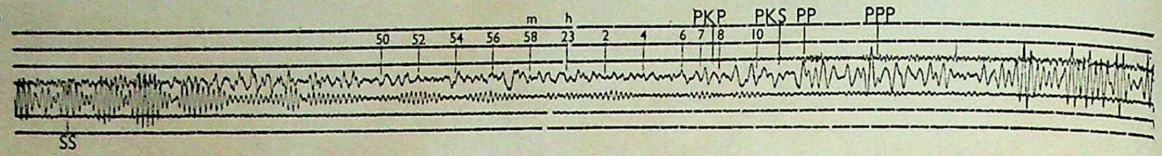

FIGURE 1 – *Seismogram from apparatus at the Royal Observatory, Edinburgh, recording the New Zealand earthquake of* 1929.

PKP *is a direct compressional wave through the earth's core.*
PKS *is a compressional body wave through the earth's core transformed to a transverse wave for the last part of its journey.*
PP *is a once-reflected longitudinal wave.*
PPP *is a twice-reflected longitudinal wave.*
SS *is a once-reflected transverse wave.*

essential idea is that a heavy mass, forming part of a dynamical system, is set in motion by the earth waves relative to its support and to the recording mechanism. Most seismographs employ a horizontal pendulum. If the axis of rotation of a pendulum is gradually changed from the horizontal to the vertical position, the effective part of gravity in controlling the rotation about that axis becomes progressively less. When the axis is almost vertical the pendulum, then nearly horizontal, is approaching instability and a long period of vibration becomes possible. A great static sensitiveness can be obtained, but heavy damping is required to diminish the effect of the free motion of the pendulum. A large magnification of the small earth motions is essential, and it is on the methods employed for magnification and damping that the efficiency of a seismograph depends.

Two horizontal seismographs are usually employed to measure the horizontal displacements in two perpendicular directions and to determine the azimuth of the epicentre. To measure the vertical movement of the ground it is usual to employ a horizontal pendulum, supported at a point between the axis and the weight by a vertical helical spring. A long period combined with stability is more difficult to obtain with a vertical than with a horizontal seismograph.

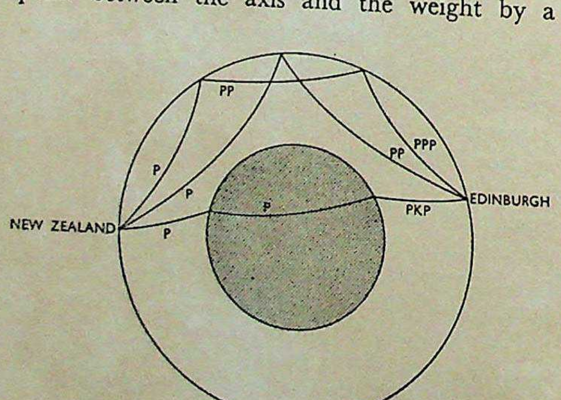

FIGURE 2 – *Section through the earth, showing the paths of some of the waves resulting from the New Zealand earthquake of* 1929. *Lettering as in figure* 1.

The most sensitive and efficient seismographs are probably those of the Galitzin type, both horizontal and vertical, which employ electromagnetic damping up to the limit of aperiodicity. Increased magnification is obtained by the use of electromagnetic recording. The Wiechert horizontal seismograph employs a very large mass (about 1000 kg) supported as an inverted pendulum by flat Cardan springs, stability being obtained by small horizontal controlling springs. Variable air damping is used, and both components are measured with the one instrument. The Milne-Shaw horizontal seismograph is a simple horizontal pendulum, using a small mass, a long light arm to give magnification, and photographic recording. If the damping is inadequate, the records are affected by the natural periodicity of the pendulum.

The seismogram obtained at the Royal Observatory, Edinburgh, for the Buller, N.Z., earthquake of 1929 (figure 1) shows several waves quite clearly. The interpretation is placed next to the trace. *PKP* is the most direct compressional wave which has come through the earth's core. *PKS* is a similar wave transformed to a transverse wave for the last part of its journey. *PP* is a longitudinal wave, once reflected at the earth's surface, while *PPP* is a similar wave twice reflected. *SS* is a transverse wave once reflected at the earth's surface. Figure 2 shows the paths of some of these waves through a section of the earth. The S-waves follow similar paths in the part outside the core. The remainder of the seismogram consists of multiple reflections, and waves which have travelled along the surface of the earth. Seismological observatories throughout the world prepare bulletins of their interpretations, which are sent to the International Seismological Summary Office, now at Kew Observatory. Here they are collated, and earthquake foci and times of origin are

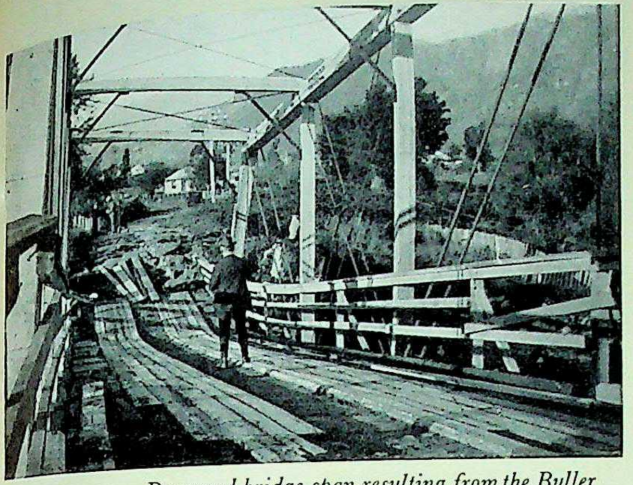

FIGURE 3 – *Damaged bridge span resulting from the Buller earthquake of June* 1929.

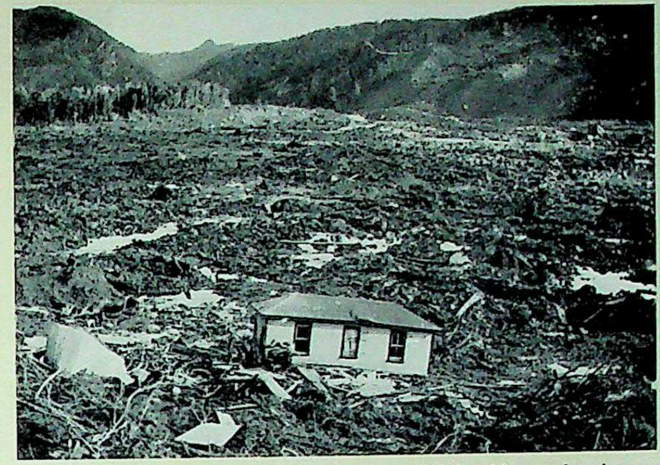

FIGURE 4 – *Slip, three miles south of Murchison, showing wrecked house.* (*Buller earthquake, June* 1929.)

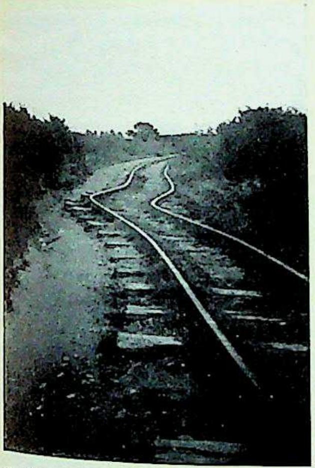

FIGURE 5 – *Bent railway lines near Westport.* (*Buller earthquake, June* 1929.)

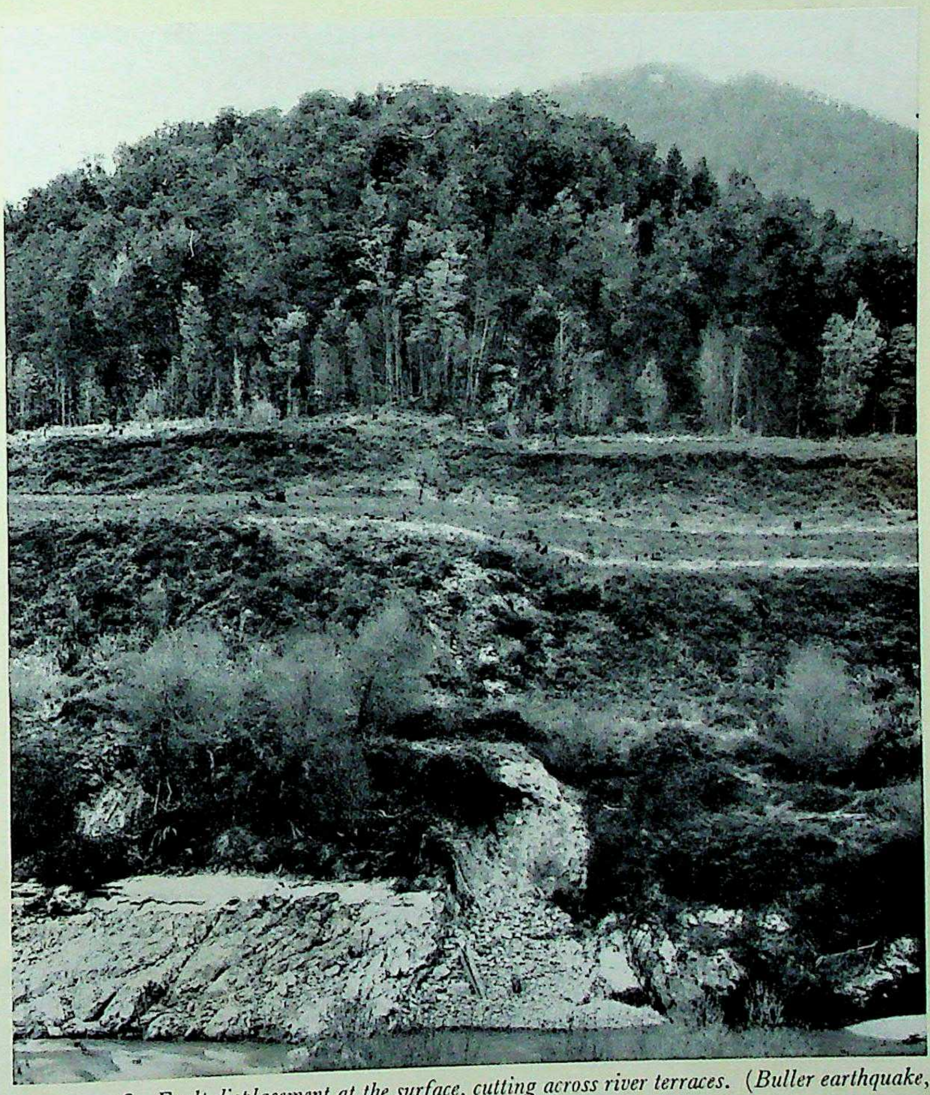

FIGURE 6 – *Fault displacement at the surface, cutting across river terraces.* (*Buller earthquake, June* 1929.)

(*Figures 3–8 are reproduced by courtesy of the Dominion Observatory, Wellington, New Zealand.*)

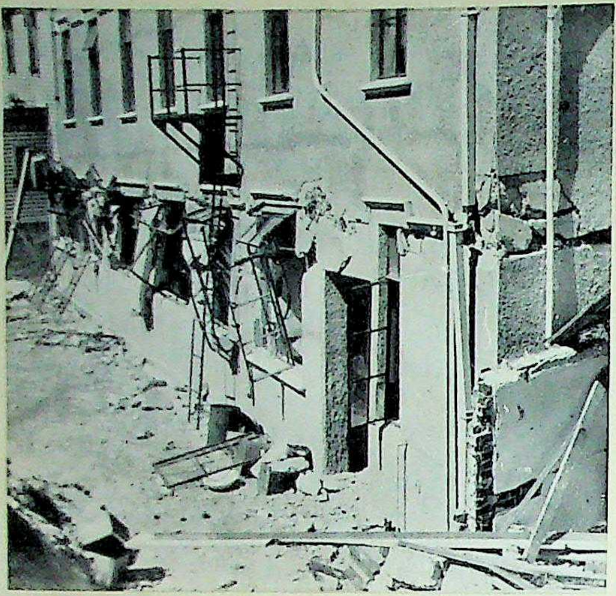

FIGURE 7 – *Roman Catholic Seminary, Greenmeadows, New Zealand, showing damage.* (*Near epicentre of earthquake of February* 1931.)

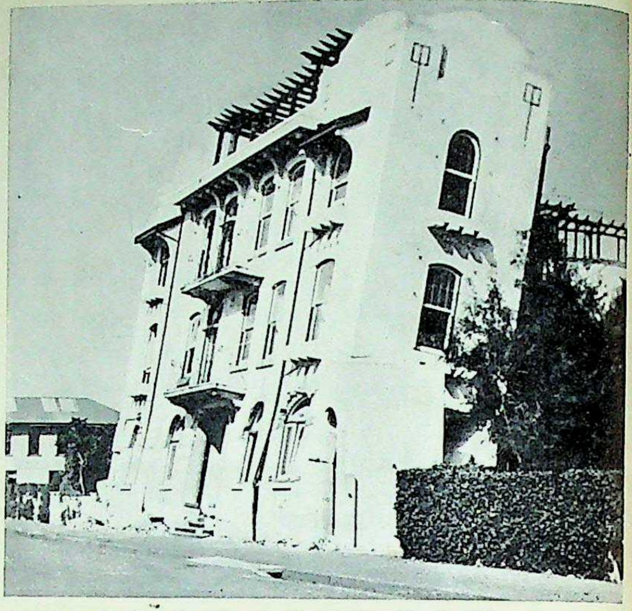

FIGURE 8 – *Dr Moore's Hospital at Napier, New Zealand, tilted and destroyed by the February* 1931 *earthquake.*

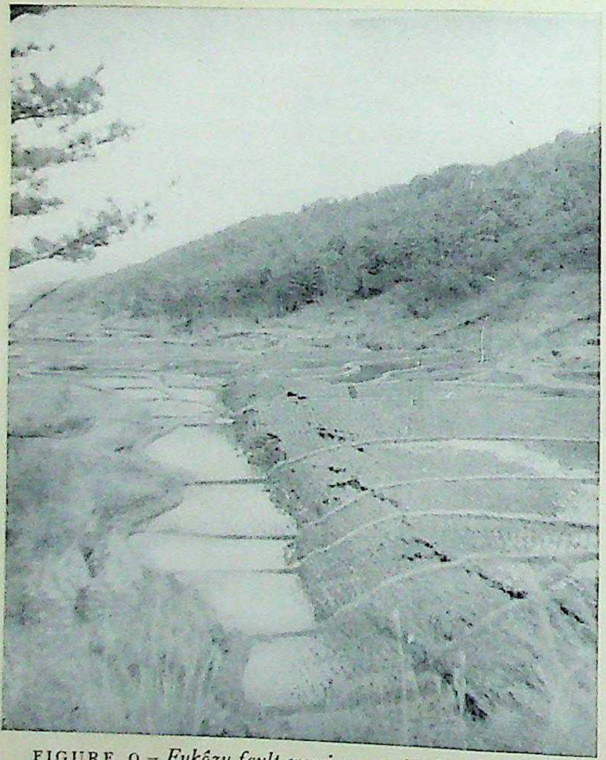

FIGURE 9 – *Fukôzu fault crossing a paddy field.* (*Mikawa earthquake, January* 1945.) *See also figures* 11–13. (*By courtesy of Dr Hiromichi Tsuya.*)

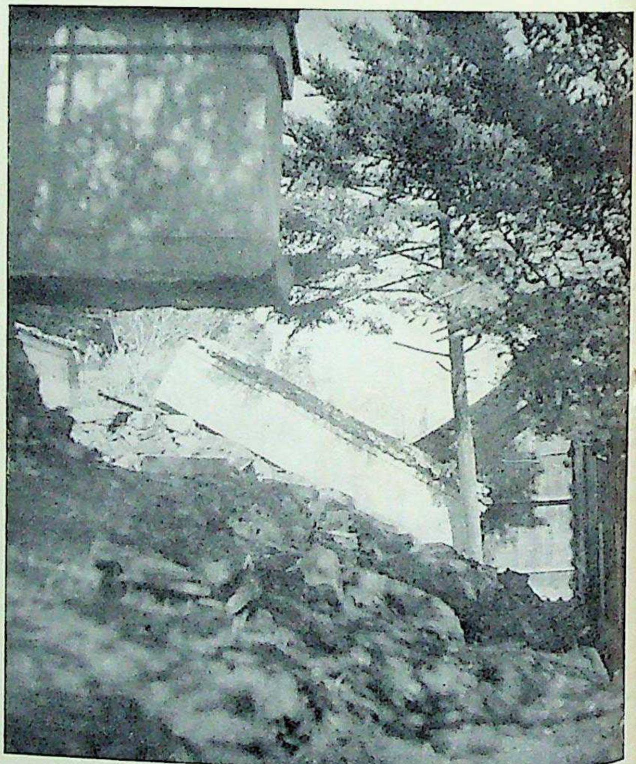

FIGURE 10 – *Fukôzu fault line, showing damage to Shinto shrine.* (*Mikawa earthquake, January* 1945.) *See also figures* 11 *and* 14. (*By courtesy of Dr Hiromichi Tsuya.*)

determined. Since this work is at present some eleven years behind earthquake occurrence, useful preliminary calculations on foci and origin-times are carried out and published by (1) The United States Coast and Geodetic Survey, Washington, D.C., (2) The International Seismological Bureau, Strasbourg, and (3) The Jesuit Seismological Central Station, Saint Louis, U.S.A. The first normally reports within days and the other two within a few weeks of the occurrence of the shock.

All these stations provide most valuable data for the research worker interested in the deep structure of the earth, with its various discontinuities, the roots of mountains, and continental and oceanic structure. Instrumental timekeeping and recording at many observatories throughout the world are so good that it has become worth while to examine the seismological implications of aeolotropy (discontinuity of properties) in continental structure [4].

EARTHQUAKE GEOGRAPHY

When the epicentres of all well-authenticated earthquakes, whenever they occurred, are plotted on a world map, most of them are found to lie in zones associated with Tertiary or recent mountain-building. Certain other areas are found to be almost free from earthquakes. Since earthquakes are known to recur in approximately the same epicentral areas, it becomes important to know where these zones are, so that the seismicity of any area in the world may be assessed.

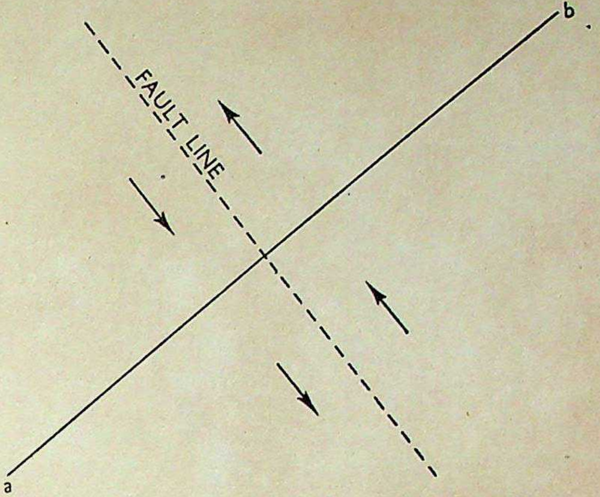

FIGURE 12 – *Ground plan to illustrate figures 9 and 13. Horizontal movement of 1·3 metres along Fukôzu fault due to Mikawa earthquake of 13th January, 1945.*

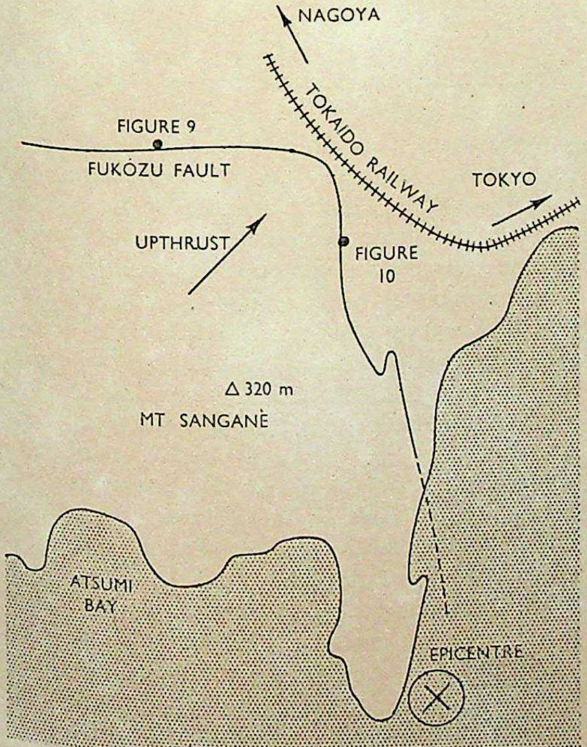

FIGURE 11 – *Sketch map showing the course of the Fukôzu fault (see figures 9 and 10), which became evident after the Mikawa earthquake of 13th January, 1945. (Scale 1 : 90,000 approx.)*

Earthquakes occur most frequently in those regions of the earth's surface where geological evidence shows that slow secular movements of the crust are still in progress, as in the Himalayas and the western coastal regions of America, or along the steeper flexures in the earth's surface, such as Japan, where there are high mountains in close proximity to great ocean depths.

One zone of earthquake activity apparently completely surrounds the Pacific Ocean, though possibly it does not include the Antarctic. The mid-Atlantic ridge is a seismic zone, and sends off a branch at right angles to itself through the Mediterranean Sea and Turkey to the Pamir Mountains, where the zone divides. The strongest branch runs along the Himalaya Mountains to Thailand and thence by way of Indonesia to the circum-Pacific belt. Another branch goes into mid-China.

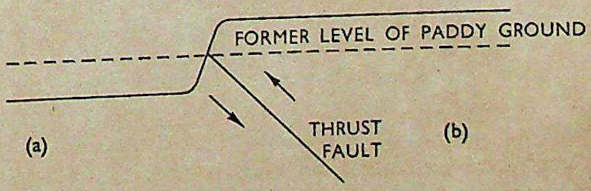

FIGURE 13 – *Vertical section to illustrate figures 9 and 12. Vertical movement of 2 metres along Fukôzu fault due to Mikawa earthquake of 13th January, 1945.*

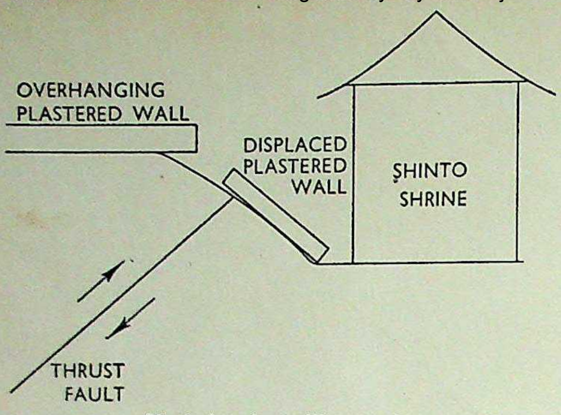

FIGURE 14 – *Vertical section to illustrate figure* 10, *showing damage to buildings along Fukôzu fault. Mikawa earthquake of* 13*th January*, 1945.

It must not be thought that all earthquakes have the same magnitude and depth of focus. Formulae for the calculation of magnitudes from instrumental recordings have been given by Gutenberg [5, 6], and it is considered that the same forces which cause earthquakes with surface foci also cause those which have the deepest known foci.

It appears probable, therefore, that faulting occurs at this great depth in the earth. Faulting at depth naturally causes permanent displacements at the earth's surface, where further faulting often consequently takes place. Figure 6 shows fault displacement occasioned by the Buller, N.Z., earthquake of June 1929; it will be seen how the fault cuts across river terraces.

I am indebted to Dr Hiromichi Tsuya for details of the remarkable Fukôzu fault which formed during the Mikawa earthquake of 13th January, 1945 [7]. This earthquake was one of the five most destructive Japanese earthquakes since 1943; it had an epicentre about latitude 34° N, longitude 137° E, near Atsumi Bay, west-south-west of Tokyo. It caused the deaths of 1961 people and injured many more. It totally destroyed 5539 houses and damaged over twice that number. The remarkable thing about the 9 km-long Fukôzu fault is that it turns almost 90° in plan in its middle course (see figure 11). Moreover, the fault line has an S-bend in one limb.

The fault itself is a reverse fault or thrust with the south-west side raised relatively to the north-east by vertical displacement of 2 metres. The horizontal displacement is much less and at most amounts to only 1 metre. The appearance of the fault varies with the nature of the surface rocks. In hard ground it usually forms steep overhanging cliffs, whereas in loose soil it appears either as a simple flexure of the ground or as a crumpled down-slope. The plane of the fault dips 50–70° to the south in the north wing and to the west in the south wing. It is probably not a new fault geologically; the northern wing separates structurally different parts of the upper Palaeozoic metamorphics (mica-schist and quartz-schist on both sides); the southern wing passes between metamorphics on the west and more or less schistose hornblende-biotite-granite on the east. There can thus be little doubt that the earthquake fault has been formed by accentuated and renewed crust movements along the pre-existing geological faults.

The area of earthquake damage to buildings was almost confined to the south-west side, except for a narrow zone along the fault. The Tokaidô railway line suffered no damage from the earthquake, although it is only 150 metres distant on the north-east side of the fault at Fukôzu. Accordingly, from this and other evidence it may be fairly inferred that, at the very moment of the earthquake, the Sangané-san mountain block, bounded by the fault on its northern and eastern sides, was up-thrusted forward in a north-easterly direction (figures 9, 10, and 12–14).

THE CAUSE OF EARTHQUAKES

The fundamental cause of earthquakes lies in the deep interior of the earth, and is probably connected with adjustments necessitated by the transference of heat. This heat may be original heat, radioactive heat, or heat due to chemical, frictional, or other causes. The interior adjustment calls for movement in the solid exterior involving compression-tension or shearing forces, or both, and this goes on until the elastic limit of the rock is reached, when rupture occurs. This rupture has occurred in the past at depths as much as 720 kilometres from the earth's surface, but not below that level. The initial point of rupture is at the present time considered to be the earthquake focus, and elastic waves appear to spread outwards in all directions from that point.

The point on the earth's surface immediately above the focus is known as the epicentre of the earthquake. The elastic waves radiated from the earthquake focus disturb, either temporarily or permanently, the equilibrium of the rocks through which they pass, and may initiate the adjustment of surface blocks to the new underground conditions. This results in surface faulting. Gravity anomalies, and active ground tilt, as measured by tiltmeters, may indicate potential or increasing deep-seated stresses portending possible future earthquakes.

ENGINEERING CONSIDERATIONS

The damage caused by earthquakes to buildings, bridges, and so forth, calls attention to the need for studying the construction of earthquake-resistant structures. Something may be learned from photographs of earthquake damage as shown in figures 7 and 8, of the Hawke's Bay, New Zealand, earthquake of February 1931. It appears preferable, however, to get an idea of the nature of the forces involved, and then to design from first principles a structure to withstand such forces. The data needed include the accelerations —from which forces may be obtained by applying Newton's second law of motion; velocities—from which to determine momenta and kinetic energy; the displacements—for stability considerations; and the periods of the earthquake motion—for considerations of resonance.

Over forty accelerographs have been set up by the United States Coast and Geodetic Survey, well distributed in regions subject to earthquakes on the western side of America. An accelerograph is so called because its natural period of 0·1 second is relatively short compared to that of the principal earthquake waves causing damage. Probably the best accelerograph record so far obtained is that of the Imperial Valley earthquake of 18th May, 1940, obtained at El Centro, within 7 miles of a place where there was a fault-displacement of 12 feet due to the earthquake. By integration of this record the velocities and displacements were obtained [8], and it has been found possible to reproduce these movements satisfactorily on a shaking table.

Generally speaking, well-tied, single-storey buildings constructed of good materials, and with natural periods of vibration that do not coincide with those of the principal earthquake waves which cause destruction, have been found to serve best in areas subject to earthquakes, unless other conditions preclude such construction.

In many towns and cities in earthquake zones, where financial considerations might incline individuals to neglect earthquake-proof construction, building codes have been formulated by the city authorities, and, additionally, insurance companies likely to be concerned with coverage of this kind have their own minimum conditions [9, 10].

There are, finally, two aspects of general seismology which demand mention, and which now have their own literature. The first is seismic prospecting, in which explosions in the ground are made to send primary and other earthquake waves through the ground, whence they are received on specially constructed seismographs. The interpretation of the seismograms so obtained, assisted by geological extrapolation, enables the prospector to delineate underground structure and so save much in drilling-costs. The method has been found successful where superimposed strata have very different elastic properties, and in particular in oilfields in the Near East, of the U.S.A., Mexico, and Great Britain (Nottinghamshire). The second aspect is that of microseisms. These are not caused by earthquakes, but are general ground-unrest due to a variety of causes. The dominant ones picked up by seismographs of 3 to 7 or 8 seconds period have been found to be caused by storms at sea. The path of the storm centre, or point of origin of the microseisms, can be traced by the use of the tripartite seismograph station, and thus the seismograph serves as a meteorological instrument. This has been found extremely useful in the Caribbean Sea and elsewhere [11, 12] for weather-forecasting for marine and aviation purposes, and for tracking and timing the approach of hurricanes.

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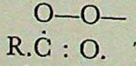
The reactivity of free radicals in solution

H. W. MELVILLE

The idea that free radicals can exist is now familiar and well established, but the earliest known examples, such as triphenyl, are relatively unreactive, and the reactions they can bring about are limited. That radicals play a part in gas phase reactions has been known for many years, but only recently has the quantitative behaviour of radicals in solution been studied. Professor Melville, who has carried out much work on the subject, describes some of the results obtained. They are likely to lead to more precise theories of organic reactions.

It seems to be an established fact that as more and more non-ionic reactions are studied, both in the liquid and in the gas phase, their mechanism proves to involve free atoms or radicals. The general reason appears to be that this mechanism is an energetically economical way to accomplish a given kind of transformation. For example, consider the oxidation of an aldehyde (R.CHO) to a per-acid (R.COOOH). The simplest possible way for this to occur is by adding a molecule of oxygen directly to the aldehyde. No doubt each molecule would need to acquire a considerable amount of energy for this transformation, but that can always be done by the collisional processes existing in any system in which energy is distributed according to Maxwell's law. This kind of reaction would be bimolecular, and the rate would be proportional to the concentration of the aldehyde and of the oxygen. Furthermore, the rate would not be affected by environment nor by the presence of other kinds of molecules. In actual fact, the rate is independent of oxygen concentration, and it can be reduced to very small values by the addition of comparatively small amounts of oxidizable bodies like quinol. These facts can be explained only if we assume that by some mechanism a hydrogen atom is abstracted from the aldehyde, thus: $R.CH{:}O \rightarrow R.C{:}O$. Then oxygen, being itself really a bi-radical, at once adds on to the aldehyde radical:  $\mathrm{R.}\overset{\mathrm{O{-}O{-}}}{\dot{\mathrm{C}}}\mathrm{\,:\,O}$. This peroxide radical then removes a hydrogen atom from another aldehyde molecule, thus forming the per-acid R.COOOH and regenerating the aldehyde radical. The process does not continue indefinitely, but comes to a stop when two peroxide radicals react with each other.

Many other examples have been studied, and overwhelming evidence has been brought together in support of the existence of radicals in solution. The question that is now being actively considered is how to determine the nature and concentration of the radicals involved, so that the problem of measuring the rate of interaction of radicals with molecules and other radicals may be solved quantitatively. If this can be done, then a new chemistry of radical reactions will arise, and the further question of relating radical reactivity to chemical structure and environment will offer much scope for a better understanding of the nature of chemical reactivity as a whole.

DETERMINATION OF RADICAL CONCENTRATIONS

The radicals concerned in oxidation, in the addition-polymerization of ethylenic derivatives, and in the addition of hydrogen bromide, carbon tetrachloride, etc., to olefines are very reactive, and their concentrations must be relatively minute. Thus no direct physical method (such as the measurement of paramagnetism) is likely to be sensitive enough to demonstrate their existence. On the other hand, when the reaction is going steadily the rate of formation of radicals is equal to their rate of destruction. If I is the rate of formation, by whatever mechanism, and $k_t(P)^2$ is their rate of interaction, k_t being simply a bimolecular coefficient, then $I = k_t(P)^2$ and $(P) = (I/k_t)^{\frac{1}{2}}$. Thus to solve the difficulty it is necessary to devise some means of counting the number of radicals produced, and also some means of observing the rate at which radicals react with each other and therefore disappear. The first part of this problem has been under review for many years; the second part has not been solved accurately until comparatively recently.

Probably the most direct way of getting information about the rate of production of radicals is to suppress the reaction altogether by the addition of a powerful inhibitor. This can be done in the polymerization of various derivatives of ethylene such as vinyl acetate ($CH_2{=}CH.O.COCH_3$), where benzoquinone will act in this fashion. When the inhibitor is removed, the reaction proceeds at a speed precisely identical with that of the normal reaction. This simply means that the quinone reacts with all radicals formed but does not affect their rate of formation.

An alternative method consists in retarding the reaction; for example, the oxidation of aliphatic aldehydes is retarded by quinol, which is again chemically destroyed. In this case the radicals, probably R—OO—, interact with the quinol instead of with each other. Thus for each radical initially generated one molecule of quinol is destroyed.

A third method, which is applicable only to polymerization reactions, consists in measuring the number of polymer molecules produced, assuming each polymer molecule to be the result of the addition of a radical to the monomer, which in turn forms a new radical, and polymerization then continues:

$$R + CH_2{=}CHX \rightarrow R - CH_2 - CHX -, \text{ etc.}$$

The problem of measuring the rate of combination of radicals is much more difficult. If the source of radicals is quite suddenly cut off, the radical concentration will at once start to diminish, and any reaction that these radicals may induce in the system will diminish proportionately with it. Fortunately, this can readily be achieved, if the radicals are produced photochemically, by the sudden discontinuance of irradiation. The experimental difficulty is then to observe the decrease in rates of reaction over relatively short intervals of time, because the radicals are short-lived in character. Until recently, this could not be done directly, but an older method has proved useful in this connection [1]. It consists in using intermittent radiation, the period between flashes being variable, but accurately measurable. Qualitatively, the principle is as follows. If a flash of radiation is absorbed by a system a certain concentration of radicals will be built up. In the dark period this concentration will decay. But if another flash of light impinges on the system before the concentration of the first crop of radicals falls to zero, then the second crop of radicals will by their presence accelerate the removal of the first lot by interacting rapidly with them. This effect will depend on the time-interval between the flashes. The result is that the speed of the reaction will be a function of the interval between flashes. By working out the theory of the method exactly, it becomes possible to calculate the life-time of the radicals under the conditions of steady illumination [2]. The average life-time of a radical, however, is equal to $(P)/k_t(P)^2$, i.e. the ratio of the concentration to the rate of removal. But $k_t(P)^2=I$, and thus (P) can be calculated.

These life-times have turned out to be a good deal longer than was originally expected. In the gas phase it is rare to find simple aliphatic radicals lasting for more than 10^{-3} second, but in some polymerization reactions, such as that of styrene ($CH_2{=}CH.C_6H_5$), under favourable circumstances radical life-times of the order of 10^2 seconds have been observed. These much longer life-times make it practicable to observe directly the decay of chemical reactivity after the photo-exciting radiation has been cut off, provided sufficiently small amounts of reaction can be measured [3]. For example, in polymerization reactions there is a volume decrease of 10–20 per cent. By using sufficiently sensitive dilatometers the accumulation of 1 part in 10^7 of polymer can be detected, and thereby the decay of radical concentration can easily be measured directly over the periods of a minute or more. Similarly, the polymer molecules formed in the decay contribute to the viscosity of the system, and since viscosity is very sensitive to the addition of small amounts of polymer, the increase in viscosity can be used to observe the decay of radical concentration [4]. Radical concentration may also be measured by observing, with the help of very sensitive instruments, changes in the refractivity of a liquid or in the dielectric constant at high frequencies (100 megacycles/second). The radical concentrations produced in polymerization systems are never large; 10^{-8} to 10^{-10} mole/litre is a common range, the concentration of the monomer being of the order of 10 moles/litre.

The evolution and development of these new methods of analysing the mechanism of reactions throw open a wide field of inquiry, and thus provide a wealth of information about radical behaviour which could not possibly be obtained by any normal method of approach. Perhaps the simplest question is the way in which radicals react with each other. In particular, with polymerization reactions one of the first problems is whether the rate varies with the size of the polymer radical. It is a relatively easy matter to change the size of a radical, but the surprising result is that reactivity is practically independent of size, e.g. for vinyl acetate radicals $—(CH_2—CH.O.COCH_3)_n—$ an increase in the number of monomer units in the radical from 176 to 352 results in only a slight decrease of the bimolecular velocity coefficient for interaction—from $3{\cdot}1 \times 10^9$ litres moles^{-1} sec^{-1} to $2{\cdot}5 \times 10^9$ [2]. This is not altogether unexpected, for it is known that such radicals are well extended in solution, and, further, that the chain of atoms has very considerable flexibility, owing to more or less free rotation of groups around the single bonds forming the backbone of the radical. The end of the radical thus possesses a high mobility, and should behave almost like a small isolated radical. The analogy cannot be carried too far, for if the medium is allowed to become viscous the speed at which radicals interact is materially cut down, because of their decreased mobility. Presumably, therefore, in an almost solid medium this life-time could become exceptionally large; there is recent evidence to that effect. If, however, we return to the analogy of small radicals, it is worth while considering how fast such radicals could interact, assuming that no energy is required for the occurrence of reaction. If reaction rates are expressed in terms of moles, litres, and seconds, the maximum possible value of the bimolecular coefficient is 10^{11}. In table I some interaction coefficients are shown for a variety of monomers. In every case the values are very much less than 10^{11}. This is not surprising, because it will not be an easy matter for the radicals to become oriented in such a fashion that chemical interaction can take place. The unusual feature is that the reactivities vary so much among the series. It points to the fact that chemical structure must have an important bearing on a relatively simple kind of reaction. On the other hand, if we turn to oxidation reactions in which the radicals involved are of the type RO_2, we find a more normal value for the interaction constant—but now the nature of the group R has no important effect on reactivity.

Chemically, the production and destruction of radicals is relatively unimportant except in so far as the control of rate of reaction is concerned. When a radical interacts with a monomer the action is one of addition, e.g.

$$R-CH_2-CHX + CH_2{=}CHX \rightarrow$$
$$R-CH_2-CH-CH_2-CHX-,$$

and the radical is reproduced. This cycle of events may occur 10,000 times. Similarly, in oxidation reactions the reaction of the RO_2 with the RH compound being oxidized does not result in destruction. Thus the rate of overall reaction can be very simply expressed as the rate at which radicals will use up monomer on the one hand and RH molecules on the other, or, put more compactly, $Rate = k(P)(M)$, where k is another simple bimolecular coefficient characteristic of the radical-molecule reaction under investigation, i.e. a numerical value of reactivity. Since (P) is now known, k can be calculated. As with the radical reactions, the maximum value of k would again be 10^{11}, but the actual values in table II are for a variety of polymer systems very much smaller. There are two reasons for this behaviour. These reactions do not occur without energy of activation, even though radicals are involved. This energy is due to the repulsion that a radical experiences in approaching the monomer for the act of addition. It can be evaluated; the figures are given in column 3. This factor can be extracted from the velocity coefficient in the form $e^{-E/RT}$, leaving thus a factor independent of temperature which is still much less than 10^{11}. It is therefore clear that configurational effects are very important in determining radical-molecule reactivity too.

Polymer radicals do not always add to monomer. Occasionally they abstract a hydrogen atom, thus:

$$R- + CH_2 = CHX \rightarrow RH + CH_2 = CX.$$

Once again radical reactivity is not destroyed, but naturally the continuity of the polymer chain is necessarily interrupted if the reaction goes in this fashion. This kind of dehydrogenation reaction has a serious effect in limiting the size of the polymer that can be synthesized. Its probability relative to that of polymer growth can be estimated by making simultaneous measurements of the number of monomer units in the polymer and the number of monomer units polymerized for each radical initially produced. For example, with styrene at 25° C the relative probability of transfer to growth is 10^{-3} [5]. If the radical so produced is not reactive, as occurs with allyl compounds,

TABLE I

Monomer	*Interaction coefficient for polymer radicals (litres moles^{-1} seconds^{-1})*
$CH_2{=}CH.COOC_4H_9$ ..	$1{\cdot}8 \times 10^4$
$CH_2{=}CH.C_6H_5$ ..	$7{\cdot}9 \times 10^6$
$CH_2{=}C(CH_3)COOCH_3$	$2{\cdot}7 \times 10^7$
$CH_2{=}CHO.COCH_3$ ..	$3{\cdot}9 \times 10^8$
Oxidation reaction	*Interaction coefficient for RO_2 radicals*
Cyclohexene	$0{\cdot}95 \times 10^6$
1-Methyl-cyclohexene ..	$0{\cdot}50 \times 10^6$
Dihydromyrcene	$0{\cdot}65 \times 10^6$
Ethyl linoleate	$0{\cdot}50 \times 10^6$

TABLE II

Monomer	Polymer radical monomer reaction coefficient at 25° C	Energy needed for radical growth (in kilocalories)	Collision factor when energy has been supplied
$CH_2{=}CH.COOC_4H_9$	20	6·0	$5{\cdot}1 \times 10^5$
$CH_2{=}CH.C_6H_5$	40	6·0	$9{\cdot}0 \times 10^5$
$CH_2{=}C(CH_3)COOCH_3$	200	5·0	$9{\cdot}5 \times 10^5$
$CH_2{=}CH.O.COCH_3$	800	4·4	$1{\cdot}8 \times 10^6$

($CH_2 = CH - CHX$), molecular growth will also stop at the transfer stage. The degree of polymerization is then very seriously limited, and high polymers cannot be prepared.

When solvents are added to the system they may act as inert diluents, and any variation in rate of formation and molecular weight of the polymer is wholly due to mass-action effects. More often, however, transfer occurs by the removal of hydrogen (or perhaps halogen), the radical so formed being capable of reacting with the monomer so rapidly that no other fate befalls it. Competitive factors at once operate again. A polymer radical has a chance of either adding on another unit, or of reacting with the solvent, in which case the growth of that particular polymer radical is stopped. The quantitative measurement of the effect of solvent concentration on molecular weight gives this information, hence knowledge of the rate of polymer radical growth makes it possible to calculate the absolute rate of the transfer process. It is difficult to write down the chemistry of the process, but a fair presumption to make is that the hydrogen (in a hydrocarbon) which is most weakly bound to the carbon atom will be removed. Thus we find that the styryl radical attacks these aromatic hydrocarbons in the following order:

$$\underset{\textit{isopropyl benzene}}{C_6H_5\overset{*}{C}H(CH_3)_2} > \underset{\textit{ethyl benzene}}{C_6H_5\overset{*}{C}H_2CH_3} > \underset{\textit{toluene}}{C_6H_5\overset{*}{C}H_3} > \underset{\textit{benzene}}{C_6H_6},$$

the hydrogen atoms marked with a star being those removed. The radicals so far considered will, however, be more reactive in the opposite sense to the series for ease of transfer. It may happen that some molecules, e.g. vinyl acetate

$$(CH_2{=}CH.OCOCH_3),$$

are not particularly reactive towards radicals of this kind, and therefore some are lost by side reactions. In such cases the transfer agents begin to act as retarders of polymerization.

These studies have been successfully extended to co-polymerization of two monomers A and B in which the monomer units are built into the same macromolecule. By fixing A and studying the composition of the co-polymer formed with a variety of B monomers it is possible to evaluate precisely the reactivity of, say, a styryl radical to a whole variety of monomers. This again provides data of a reliable kind on the relationship between reactivity and molecular structure [7]. Similarly, by the study of the rate of production of co-polymer it is also possible to study the reactions between dissimilar polymer radicals. Just as interactions between like radicals are specific, so are the reactions between dissimilar radicals.

To conclude in a few words, the absolute determination of the velocity coefficients in a simple polymer reaction has led to the development of a quantitative radical chemistry the extent of which is practically unlimited. The compilation of data of this kind will provide the facts required to evolve more precise theories of organic reactions and to regulate the development of such theories.

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Book reviews

GAS SEPARATION

The Separation of Gases, *by M. Ruhemann. Pp. xii + 307. Clarendon Press, Oxford. Second edition,* 1949. 30*s. net.*

Most gases occur naturally as a component of complicated mixtures; the primary gaseous products of industrial processes contain a number of chemical species in diverse concentrations. Before they can be used it is generally necessary to alter their relative concentrations, or, in some cases, to separate the pure species.

The scientific basis of gas separation, or of altering the relative concentrations of the different species in a mixture, is to be found in the conditions of thermodynamical equilibrium developed by Willard Gibbs. That a system be in thermodynamical equilibrium with regard to a particular component requires that its partial or chemical potential be the same in each phase of the system. This condition implies a difference of concentration in the phases: a component tends to pass from a phase in which its partial potential is greater to a phase in which its partial potential is smaller.

This book gives an account of these thermodynamical principles, and of the way in which they have been applied to develop processes of gas separation. The main industrial processes depend primarily on liquefaction at low temperatures. The theory and practice of these processes are reviewed. The author then deals with the separation of air—including the production of the rare gases—and the production of hydrogen and hydrocarbons.

A. R. MILLER

A VIEW OF SCIENCE

The Freedom of Necessity, *by J. D. Bernal. Pp. xi + 437. Routledge and Kegan Paul Limited, London.* 1949. 18*s. net.*

The decay into which science fell in the second and third decades of the nineteenth century was largely a result of the reaction of the wealthy and powerful against its atheistical and Jacobin association: so Professor Bernal says. One could scarcely choose two decades more splendid for their record of scientific discovery. They saw the origin of three great modern sciences—biochemistry, histochemistry, and cytology—and the opening out of a whole new realm of organic chemistry with the discovery of benzene. Even if it could be shown that any two particular decades were periods of decay in science, we have no means of testing the truth of a dogmatic assertion that the decay was due to reactions of wealthy and powerful persons.

This is what Professor Bernal wrote about chromosomes in 1935 and reprints in the present book: 'The discovery of the mechanism of inheritance through the chromosome-theory (originally put forward by Mendel and now actually verifiable by microscopical observation) provides the material mode of transformation by which living animals develop and reproduce.' He can print this true statement (a heresy in the U.S.S.R. today) simply because he happens to live in a country where there is still freedom in science. His remark that there is no branch of human activity more dependent than science on the maintenance of liberty is confusing and deceptive to the last degree: it is contrary to the whole emphasis of his propaganda for the central direction of science.

JOHN R. BAKER

THE POTATO

The History and Social Influence of the Potato, *by Redcliffe N. Salaman, with a chapter on industrial uses by W. G. Burton. Pp. xxiv + 685, with a frontispiece, 32 plates, and 25 figures in text. University Press, Cambridge.* 1949. 50*s. net.*

This is a most unusual book. The author, whose work *Potato Varieties* (1926) is a classic, and who for more than forty years has studied the genetics and diseases of potatoes, attempts to answer such questions as what was the country of origin of the cultivated potato, what manner of people first made use of it, whence, when, and how did it first get to Europe, and how has it come about that in certain countries it replaced cereals as the main food plant, and with what result.

Evidence from prehistoric pottery suggests that long before the time of the Incas the indigenous tribes of the Andean uplands made use of tuber-bearing species of *Solanum*, among which a tetraploid hybrid, the ancestor of our potato, was the most important. Used by the Spaniards as a cheap, easily-raised food for their slaves in the silver mines, it was brought to Europe before 1570 and first grown at Seville. As a curiosity and luxury food it spread in western Europe, but was only slowly adopted as a popular article of diet. Recognizing the conservatism of peoples in the matter of food, Salaman believes that radical changes in diet are brought about only when factors, economic and political, compel a change, however suitable the soil and climate may be to the new crop. This thesis he develops for several countries, chiefly Britain and Ireland. The book is a mine of information, made readily accessible by a full index (40 pages), and a bibliography of some 800 references.

T. G. B. OSBORN

HETEROPOLAR AND OTHER BONDS

Molecules and Crystals in Inorganic Chemistry, *by A. E. van Arkel. Pp. ix + 234. Butterworth's Scientific Publications Limited, London.* 1949. *Translated by J. C. Swallow.* 17*s.* 6d. *net.*

Professor van Arkel's book has had a great success in the universities of the Netherlands, and the present translation is based on the third Dutch edition now in preparation. The author believes that a thorough grasp of the implications of the heteropolar bond provides a wide insight into inorganic chemistry as a whole. In the earlier chapters he discusses how the theory of the electrostatic bond can explain a number of phenomena in inorganic chemistry. However, he stresses the limitation of this treatment, and thereby introduces the reader to other chemical bonds which are considered in the later sections of the volume. The book is intended for students in their first year of science or medicine, but it is doubtful whether such students will have an adequate knowledge of general chemistry to derive real benefit from this book. It will, however, prove most interesting and stimulating to science students at a more advanced stage of their studies. There is no doubt that the writer is at times somewhat daring in his theoretical speculations, but this adds to the value of the text. Dr J. C. Swallow has carried out the task of translation in an exact and graceful manner. Chemists owe him a debt of gratitude for making available a scholarly and attractive exposition of a subject which is of lively interest to most chemists.

W. WARDLAW

SURFACE CHEMISTRY

Surface Chemistry: papers presented for a discussion of the *Société de Chimie Physique* and the Faraday Society, October 1947. *Pp.* 344. *Butterworth's Scientific Publications, London.* 1949. 25*s. net.*

This volume presents, in English and French, 42 papers contributed to the meeting held in honour of the veteran Henri Devaux, who contributes the first paper, describing ingenious experiments on the influence of moisture in the air on the area of films of salts and sugar on mercury. It includes papers on most branches of surface chemistry; a masterly concise summary by Guggenheim of theorems on surface thermodynamics; several others on phase changes and equilibria in surfaces; and a method of separating haemoglobin and catalase by frothing. Several papers from Cambridge attempt an attack on the complex problem of interpreting the biological action of various substances, particularly soaps and similar compounds, in terms of their surface activity. There are a number of papers on monolayers of fatty substances and proteins, and on their interaction with soluble substances; two papers on the distribution of ions near surfaces and ionic micelles; and some on technique. As usual in discussions, some of the papers describe work already published, but the volume is of great value, and indispensable to serious students of surface chemistry. It should also be studied by biologists interested in physical chemistry.

N. K. ADAM

PLANTS AND INORGANIC FOOD

Inorganic Nutrition of Plants, *by D. R. Hoagland. Pp.* 226, *with* 28 *plates and* 44 *text figures. Chronica Botanica Company, Waltham, Mass., U.S.A., and Wm. Dawson and Sons, Limited, London.* 1948. $4.50 *net.*

This book contains the Prather Lectures given at Harvard and first published during 1944, when they were not obtainable in Europe. It is valuable to have them reprinted, as they contain a good general survey of the work done by Professor Hoagland and his associates in California, and of other related researches in the field of mineral plant nutrition.

The virtues of this book lie in the breadth of outlook that has characterized its author's work. He has made notable contributions to the study of soil colloids and soil solutions, with special interest in the quantitative aspects of potassium absorption and movement. He was a leader in the realization of the significance of the accumulation of ions in plant cells, and in the demonstration of the dependence of salt absorption upon the energy relations of the cells. He has added greatly to our knowledge of the relations between ion-intake and cell-metabolism, and, not least, he has been fertile in the development of improved methods. He tells of these things in this book in a simple and attractive style.

W. H. PEARSALL

INDUSTRIAL CHEMICAL RESEARCH

The Practice of Research in the Chemical Industries, *by R. H. Griffith. Pp.* 184. *Oxford University Press, London.* 1949. 12*s.* 6*d. net.*

Although the author disowns any claim to novelty, he has nevertheless successfully collected a variety of opinions, drawn from scattered sources, which he discusses in such a way as to present a connected and readable account of the aims and methods of industrial chemical research.

The sections on the recruitment, training, and welfare of staff, though familiar ground to the manager of a research department, are a timely reminder to the research worker that the efficient management of industrial research has other aspects than the purely scientific.

The place, in a work of this kind, of some of the more detailed chapters, such as those on laboratory design and on indexing systems, is perhaps questionable, and, in a field where local requirements are so diverse, broad generalizations can be misleading: it is only fair to add that the author himself obviously realizes this fact.

Taken as a whole, the book is one which is very well worth the attention of all concerned either with the carrying out of industrial chemical research or with the utilization of its results. For the student also it should provide a welcome introduction to the special problems which arise from the application of research to industry.

L. W. CODD

X-RAY DIFFRACTION

The Optical Principles of the Diffraction of X-rays, *by R. W. James. Pp. xv* + 623, *with* 224 *half-tone and line illustrations. G. Bell and Sons Limited, London.* 1948. 80*s. net.*

It is not far short of twenty years since the Braggs and their collaborators first discussed the preparation of a series of volumes on 'The Crystalline State.' Vol. I, a general survey by W. L. (now Sir Lawrence) Bragg, appeared in 1933, but so many preoccupations, especially the war, have since intervened that it is only now that we see the next development of the plan. In the meantime, inevitably, its early outlines have been so overspread by the advance of discovery that the present vol. II covers no more than a part of the vol. II originally proposed, and even so is longer than the author anticipated. It is certainly too long and detailed to do justice to in a short notice of this kind, and beyond listing the principal headings (the geometrical theory of diffraction by space-lattices; the intensity of reflection of X-rays by crystals; the atomic scattering factor; the anomalous scattering and dispersion of X-rays; the influence of temperature on the diffraction of X-rays by crystals; experimental tests of the intensity formulae; the use of Fourier series in crystal analysis; Laue's development of the dynamical theory; the scattering of X-rays by gases, liquids, and amorphous solids; diffraction by small crystals) we can only say that Professor James, a former member of the Bragg school at Manchester, has done an excellent piece of work and given us a notable addition to the literature of structure analysis. On looking through it, the thought was bound to occur to the reviewer that Sir William Bragg would have been proud to share again with his son the editorship which inspired vol. I.

W. T. ASTBURY

STATISTICS IN GENETICS

Biometrical Genetics, *by K. Mather. Pp. ix* + 162, *with several line diagrams. Methuen and Company Limited, London.* 1949. 18*s. net.*

The classical theory of genetics has largely dealt with cases of discontinuous variation, such as the distinction between black, yellow, and white cats. It has long been known that continuously graded variation, such as that of height in man, is also inherited in a Mendelian manner, being due to the combined effect of several genes, each by itself having only a small effect. This book deals with the recently developed methods of analysing continuous variation. Although no single gene can be studied on its own, yet by suitable statistical methods one can show the segregation, dominance, and linkage of genes. These properties are important in breeding for a continuously graded character.

The book is very lucidly written, and all formulae necessary for the analysis are carefully set out. The formulae will be strictly accurate only within certain limitations, notably that the effects of the separate genes should be exactly additive. This is unlikely in practice, but Professor Mather recognizes these limitations, and shows how errors from ignoring them can be minimized by using suitable scales of measurement.

The book has a complete set of references for further study, and is well indexed. C. A. B. SMITH

COLOURS

Colours and how we see them, *by H. Hartridge. Pp.* 158. *G. Bell and Sons Limited, London.* 1949. 15*s. net.*

In the winter of 1946–7 Professor Hartridge gave the Christmas lectures at the Royal Institution, and now presents them in the form of a book. In the first four chapters he discusses the properties of the spectrum, how colours are produced, colours and their uses, how colours are seen, and in the last two chapters describes some fascinating experiments and paradoxes with colour. The book is extremely lucid and readable, and is clearly intended for the general reader, only the most elementary scientific knowledge being assumed. The author has a way of explaining the numerous demonstrations given at the lectures so clearly that the reader who was unlucky enough not to have seen them may very readily imagine the effect. Moreover, enough information is given for him easily to repeat the experiments for himself. There can have been few books on this subject in which so many elegant demonstrations are collected.

In chapter IV Professor Hartridge briefly summarizes the anatomy and physiology of the eye, including the mechanisms of accommodation and convergence. Various theories of colour vision are mentioned, starting with that of Thomas Young. A simple account, based on Young's theory, is presented of a possible mechanism of colour vision, though it is admitted that the problem is complex and much remains to be worked out.

The book is illustrated by four halftone plates, twelve plates in colour, and a large number of line diagrams in the text. It is a pity that in a book on this topic the colour plates are not of the highest possible quality, being printed on rather absorbent paper, while some apparently suffer from imperfect registration of the three colours.

J. M. M. PINKERTON

CHEMISTRY AND ANCIENT CHINESE ARTS

The Chemical Arts of Old China, *by Li Ch'iao-p'ing, with a foreword by Tenney L. Davis. Pp. xii* + 215. *Journal of Chemical Education, Easton, Pennsylvania.* 1948. *n.p.*

Prof. T. L. Davis's last letter to the present reviewer, written shortly before his death in January 1949, ends with the words 'the history of science is the essence of humanism.' In the light of this thesis, his ardent and invaluable services in the publication of the above book are readily understandable. Authoritative works dealing with the evolution of chemistry and applied chemistry in the Orient are extremely rare—at least in the English language—and this book by Prof. Li, of the National North-Eastern University, Mukden, is therefore of peculiar value not only to chemists but to everyone interested in the arts and crafts, the economics, and the general culture of the Far East.

A short chapter on Chinese alchemy is followed by a historical survey of metals, salt, ceramic industries, lacquer, gunpowder, dyes, oils, incense, sugar, paper, alcoholic beverages, and other related subjects. In each of his fifteen chapters the author raises the curtain for a tantalizing moment upon a vast field which the reader longs to study in more detail. Among the outstanding features of a most attractively produced volume are the delicately executed line illustrations, reminiscent of the familiar willow pattern of Nanking china: the processes of making Chinese ink, for example, are shown in a series of ten charming drawings of the kind. In view of the nature of the book, an index would be of much help. An improved documentation is equally desirable: thus, in a discussion of some of Chikashige's analyses of ancient bronze objects there is no reference to this author's book on *Alchemy and Other Chemical Achievements of the Ancient Orient* (Tokyo, 1936), containing so much cognate information. But the main criticism must be that this truly fascinating book is all too short.

JOHN READ

ENGLISH FARMING

Both Sides of the Road, *by Sidney Rogerson. Illustrated by Charles Tunnicliffe. Pp.* 183, *with* 107 *black and white and* 23 *coloured plates. Collins, London.* 1949. 21*s. net.*

This book has been written by Sidney Rogerson and illustrated by Charles Tunnicliffe 'to interest those of all ages who love the country and wish to know more about the farming scene,' and it is the English farming scene which is described. First we are taken from east to west by road, and from south to north by train to give us a view of the country which is to be farmed. Then the author settles down to tell us about farming, and the story flows so freely from his pen that technical descriptions are delightful to read. His description of a poor meadow is worth quoting: 'In winter the poor meadow or pasture stands revealed as a place of short grass pimpled with warts which are grass-clad molehills or ant-heaps. . . . Brambles fling wild tentacles over the rioting hedgerows and sullen nettles flourish in the ditches. The sward will bloom first with tall daisies and rank buttercups, and later with the grey spikes and purple brush of the thistle and the tough yellow columns of ragwort. Ragwort is a sure symbol of a ragged meadow. . . . The plants which will not flourish in such a sward are the succulent and nourishing grasses which are the justification of permanent grassland.' The author gives us a very full account of the basic facts of English farming, and Charles Tunnicliffe's illustrations make long descriptions in the text unnecessary. From the illustrations we can learn at once to recognize the different breeds of cows, sheep, and pigs, and the crops growing in the fields.

Author and illustrator have combined to produce a beautiful volume—the most readable book on farming which we have seen. R. E. SLADE

'SUDBOROUGH AND JAMES'

Practical Organic Chemistry, *by J. J. Sudborough and T. Campbell James. Blackie and Son Limited, London.* 1949. *Pp.* 450. 15*s. net.*

'Sudborough and James' has been for many years a highly valued textbook of practical organic chemistry. It was first issued in 1909 and was last revised in 1924. The publication of a new edition is therefore an event which will be welcomed both by teachers and by undergraduates. To meet the changes in organic chemistry which have taken place during the last twenty-five years the book has been extensively revised, the good features of arrangement of the earlier editions being retained. In its present form it admirably suits the needs of students up to their final honours year. In addition to the well-tried old favourites, examples of more modern techniques are now to be found: for instance, chromatography, micro-analysis, chloromethylation, and the Diels-Alder reaction. The major portion of the volume consists of a systematically arranged series of preparations, but it contains also sections on quantitative methods of analysis, exercises in the determination of reaction velocities, and an outline of qualitative organic analysis. Misprints are few, although the names of Liebig, Crafts, Cannizzaro and Knoevenagel all occur incorrectly spelled. It would have been better to use the accepted *d*- or *l*- nomenclature for sugars, and more frequent references to 'Organic Syntheses' and fewer to the very early literature would have been advantageous. These are relatively minor points, however, and do not detract from the reviewer's opinion that this is a book which can be strongly recommended.

E. L. HIRST

INSECTICIDES

The Chemistry and Uses of Insecticides, *by E. R. de Ong. Pp.* 345, *with half-tones and line diagrams. Reinhold Publishing Corporation, New York; Chapman and Hall, London.* 1948. 36*s. net.*

The nature of this book can perhaps be best indicated by describing it as technological rather than scientific. It is an exhaustive survey of facts and practical details, but comparatively little space is devoted to theoretical or speculative discussion, e.g. to modes of biological action, or to relationships between molecular structure and toxicity.

Despite the publisher's claim on the wrapper that Mr de Ong's treatment is highly systematic, this absence of theoretical background has led to a far from systematic sequence of treatment. Indeed, the title itself is puzzling in this respect, for the author deals with fungicides quite as liberally as with insecticides. No attempt is made to treat these two different classes of plant-protective materials in separate sections; thus, a chapter on arsenic compounds as insecticides is abruptly followed by a chapter on the fungicidal copper compounds. Sequence of treatment seems to have been decided purely upon the dates of discovery or development of these various agricultural chemicals.

Nevertheless, the total amount of information that has been assembled is impressive. The documentation is lavish; the references given at the end of each chapter usually number more than 150. The author has wisely resisted topical temptations (prevalent in America at the time he was preparing this book) to devote an excessive attention to modern synthetic insecticides. These he has dealt with in realistic perspective. In so far as any book can remain for long an adequate reference work for this wide and fast-changing subject, Mr de Ong's survey will be a useful addition to many chemical and agricultural libraries. The high reference standard of this first edition will set him an arduous task for periodic revisions of the text.

D. P. HOPKINS

HUYGENS' COMPLETE WORKS

Œuvres complètes de Christiaan Huygens, volume XXII. *Published for the Société hollandaise des Sciences à Haarlem by Martinus Nijhoff, The Hague.*

As the whole of this edition of Huygens' works, begun in 1888, is now nearly completed, it is appropriate to draw the attention of the scientific public to this truly monumental edition.

Volume XXII deals mainly with some miscellaneous correspondence, biography, Huygens' will, and the catalogue of his library.

There exist early editions of a number of Huygens' works and also of parts of his correspondence, but these editions have long been out of print and today are very rare. They are moreover not complete, as none of the editors troubled to examine carefully all the manuscripts which Huygens bequeathed to the Leiden University Library.

The present edition is particularly important because it contains, besides the printed works (nearly all in Latin, with French translations), innumerable pages of the manuscripts, with a great number of Huygens' drawings and sketches, together with his entire correspondence, carried out with almost all the scientists of his time. Among the correspondence are many letters of a purely personal nature, so that one sees not only an excellent survey of the scientific life of the seventeenth century but also of the private life of an aristocratic Dutch family.

All the chapters are preceded by prefaces, often very elaborate, and all the texts are explained with the help of a large number of footnotes. The whole text is very fully indexed.

Many scientists who have been members of the editorial committee have contributed to the prefaces and footnotes. It is not possible to name them all, but four of them, who did by far the greatest part of the work, should be mentioned here: D. Bierens de Haan (1822–95), J. Bosscha (1831–1911), D. J. Korteweg (1848–1941), and J. A. Vollgraff.

C. A. CROMMELIN

CANADIAN CHEMISTRY

A History of Chemistry in Canada, *compiled by C. J. S. Warrington and R. V. V. Nicholls, with a foreword by T. W. Smith. Pp. x* + 502, *with* 13 *plates. Sir Isaac Pitman and Sons (Canada) Ltd., Toronto.* 1949. $4.50.

Published under the auspices of the Chemical Institute of Canada with the help of numerous specialists, this substantial work deals authoritatively with the historical development in Canada of various fields of chemistry, treated largely from the industrial point of view. The account starts with metals, and takes in such important subjects as fertilizers, mineral products, chemicals from coal, petroleum and its derivatives, products of the electric furnace, of electrolysis, of wood, of agriculture and of the sea, medicinal and fine chemicals, explosives, oils, fats, and waxes, and so forth. In each section the information is brought up to date and many statistics are quoted; thus a realistic picture is presented of Canada's great natural resources and their development as viewed by the chemist. Still further chapters deal with chemistry and public services, and with chemical teaching and research in Canadian universities and other institutions. Much detail is included of the men who have made Canadian chemistry, in both industrial and academic circles. The book is well printed, with numerous illustrations in the form of photographs, maps, portraits, and sketches.

JOHN READ

Some books received

Chemical Society Annual Reports. *Vol. XLV*, 1948. *Pp.* 379. *Chemical Society, London.* 1949. 25*s. net.*

Multi-Enzyme Systems, *by Malcolm Dixon. Pp.* 100, *with line diagrams. Cambridge University Press, London.* 1949. 7*s.* 6*d. net.*

Introduction to Radiochemistry, *by Gerhart Friedlander and Joseph W. Kennedy. Pp.* 412, *with various line and half-tone illustrations. John Wiley and Sons, New York; Chapman and Hall, London.* 1949. 40*s. net.*

Electronic Interpretations of Organic Chemistry, *by A. Edward Remick. Pp.* 600, *with various line illustrations. John Wiley and Sons, New York; Chapman and Hall, London.* 1949. 48*s. net.*

Outlines of Biochemistry, *by Ross Aiken Gortner. Third edition. Pp.* 1078, *with many line drawings. John Wiley and Sons, New York; Chapman and Hall, London.* 1949. 60*s. net.*

Quantitative Organic Analysis via Functional Groups, *by Sidney Siggia. Pp.* 152. *John Wiley and Sons, New York; Chapman and Hall, London.* 1949. 24*s. net.*

How Chemistry Works, *by Arthur J. Birch. Pp.* 218, *with various line diagrams. Sigma Books, London.* 1950. 8*s.* 6*d. net.*

Cathode Ray Tube Traces, *by Hilary Moss. Pp.* 66, *with numerous line diagrams. Electronic Engineering, London.* 1949. 10*s.* 6*d. net.*

Cosmic Ray Physics, *by D. J. K. Montgomery. Pp.* 370, *with numerous line diagrams. Princeton University Press, U.S.A.; Oxford University Press, London.* 1949. 40*s. net.*

Artificial Radioactivity, *by P. B. Moon. Pp.* 102, *with various line drawings. Cambridge University Press, London.* 1949. 12*s.* 6*d. net.*

Magnetism, *by David Schoenberg. Pp.* 216, *with several line diagrams and half-tone illustrations. Sigma Books, London.* 1949. 10*s.* 6*d. net.*

Extrapolation, Interpolation and Smoothing of Stationary Time Series, *by Norbert Wiener. Pp.* 160. *John Wiley and Sons, New York; Chapman and Hall, London.* 1949. 32*s. net.*

Recent Advances in Radio Receivers, *by L. A. Moxon. Pp.* 183, *with various line illustrations. Cambridge University Press, London.* 1949. 18*s. net.*

Engineering Structures. *Colston papers based on a symposium promoted by the Colston Research Society. Edited by A. G. Pugsley and D. R. Rexworthy. Pp.* 260, *with numerous half-tones and line diagrams. Butterworth's Scientific Publications, London.* 1950. 25*s. net* (21*s. to* Research *subscribers*).

Surface Tension and the Spreading of Liquids, *by R. S. Burdon. Pp.* 92, *with various half-tones and line diagrams. Cambridge University Press, London.* 1949. 12*s.* 6*d. net.*

Some Recent Researches in Solar Physics, *by F. Hoyle. Pp.* 134, *with various line diagrams. Cambridge University Press, London.* 1949. 12*s.* 6*d. net.*

Excited States of Nuclei, *by S. Devons. Pp.* 152, *with various line diagrams. Cambridge University Press, London.* 1949. 12*s.* 6*d. net.*

The Adsorption of Gases on Solids, *by A. R. Miller. Pp.* 133, *with numerous line diagrams. Cambridge University Press, London.* 1949. 12*s.* 6*d. net.*

Oscillations of the Earth's Atmosphere, *by M. V. Wilkes. Pp.* 74, *with various line diagrams. Cambridge University Press, London.* 1949. 12*s.* 6*d. net.*

Aviation Medicine, *by Kenneth G. Bergin. Pp.* 447, *with numerous half-tones and line illustrations. John Wright and Sons, Bristol; Simpkin Marshall* (1941), *London.* 1949. 35*s. net.*

The Theory of Inbreeding, *by Ronald A. Fisher. Pp.* 120. *Oliver and Boyd, Edinburgh.* 1949. 10*s.* 6*d. net.*

Soviet Genetics and World Science, *by Julian Huxley. Pp.* 245. *Chatto and Windus, London.* 1949. 8*s.* 6*d. net.*

Death of a Science in Russia, *by Conway Zirkle. Pp.* 319. *University of Pennsylvania Press, Philadelphia.* 1949. $3.75.

The Coming Age of Wood, *by Egon Glesinger. Pp.* 279, *with several illustrative charts. Martin Secker and Warburg, London.* 1950. 12*s.* 6*d. net.*

Alcohol, a Fuel for Internal Combustion Engines, *by S. J. W. Pleeth. Pp.* 259, *with various line diagrams. Chapman and Hall, London.* 1949. 28*s. net.*

Traité de Zoologie, *Vol. VI. Onychophores, Tardigrades, Arthropodes, Trilobitomorphes, Chélicérates. Published under the direction of Pierre-P. Grassé. Pp.* 979, *with numerous coloured plates, half-tones, and line drawings. Masson et Cie, Paris.* 1949.

Traité de Zoologie, *Vol. IX. Insectes: Paléontologie, Géonémie, Insectes Inférieurs, Coléoptères. Published under the direction of Pierre-P. Grassé. Pp.* 1117, *with numerous coloured plates, half-tones and line diagrams. Masson et Cie, Paris.* 1949.

The History of the Biochemical Society, 1911–1949, *by R. H. A. Plimmer. Pp.* 24, *with numerous half-tone plates. Cambridge University Press, London.* 1949. 2*s.* 6*d. net.*

Bergwerk- und Probierbuchlein. *From the sixteenth-century German texts, translated and edited by A. G. Sisco and C. S. Smith. Pp.* 196, *with numerous line drawings. American Institute of Mining and Metallurgical Engineers, New York.* 1949. $5 *net.*

The Personality of William Harvey, *by Geoffrey Keynes. Pp.* 48, *with eight portraits. Cambridge University Press, London.* 1949. 5s. *net.*

Crucibles: The Story of Chemistry, *by Bernard Jaffe. Third edition, revised and enlarged. Pp.* 480. *Hutchinson's Scientific and Technical Publications, London.* 1950. 18*s. net.*

Mathematics and the Imagination, *by James Newman. Pp.* 380, *with numerous line diagrams. G. Bell and Sons, London.* 1949. 15*s. net.*

The Infancy of Speech and the Speech of Infancy, *by Leopold Stein. Pp.* 209, *with several line drawings and half-tone illustrations. Methuen and Company, London.* 1949. 21*s. net.*

Snowdonia, the National Park of North Wales, *by F. J. North, Bruce Campbell and Richenda Scott. Pp.* 469, *with* 56 *colour plates,* 48 *black and white photographs, and* 6 *maps and* 26 *diagrams. Collins, London.* 1949. 21*s. net.*

Glass-to-metal Seals, *by J. H. Partridge. Pp.* 238, *with numerous half-tones and line diagrams. The Society of Glass Technology, Sheffield.* 1949. 35*s. net.*

The Power and Limits of Science, *by E. F. Caldin. Pp.* 196. *Chapman and Hall, London.* 1949. 12*s.* 6*d. net.*

ENDEAVOUR

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René Descartes (1596–1650)

The mutual influence of French and British thought and discovery in the development of modern science is a matter of history. Lavoisier's synthesis of chemical philosophy, founded partly on his own researches and partly on the experiments and discoveries of his contemporaries Black, Priestley, and Cavendish, is perhaps the most notable example. The present year, marking the tercentenary of the death of Descartes, recalls not only one of the inaugurators of modern science, but one who much admired his British contemporaries and greatly influenced their successors.

The principal works of Descartes are *Le Discours de la Méthode* (1637), containing his *Géométrie*, which marked the foundation of analytical or coordinate geometry; *Meditationes de Prima Philosophia* (1641); and *Principia Philosophiæ* (1644).

Descartes read and praised Bacon's *Novum Organum* (1620), but, unlike Bacon, considered that science would best advance by deduction rather than by induction, and by deduction only from what could be accepted as certain because it was indubitable—a view which is expressed in the well-known phrase, *Cogito, ergo sum*, but which might have been more exactly conveyed as *Dubito, ergo sum*. Also unlike Bacon, he realized the importance of mathematics in the furtherance of science; and once again unlike Bacon, he thought very highly of Gilbert's *De Magnete* (1600), and himself formulated the first scientific theory of magnetism. For Harvey's *De Motu Cordis* (1628) he had the greatest admiration.

His foundation of analytical geometry, his studies on motion, his work on refraction and the rainbow, his opposition to explanations that assumed occult qualities, his aim of basing all physical studies on mechanics, and his contention that animals were 'machines,' characterize him as one of the moderns. He was, indeed, one of the first 'mechanical' philosophers. He led science away from an Aristotelian world, and his system was replaced only by that of Newton.

Descartes considered that matter was continuous and that the world was a *plenum*, in contradiction to those who had begun to adopt a revived Greek atomism, and who argued that the world was composed of atoms and void. In his theory of vortices, the motion of a planet in its orbit was maintained by the vortex motion of a material filling all space.

These two ideas, a continuous but corpuscular matter filling all space, and a universe of vortices, were eagerly discussed among his successors in Britain. Walter Charleton, who described Descartes as 'a Wit transcendently acute,' reveals the influence of Cartesianism in his *Physiologia* (1654), the first English book on atomism, in writing that 'the opinion [on vision] of the excellent *Monsieur Des Cartes*, . . . with a kind of pleasant violence, hath so ravisht the assent of most of the Students of Physiology [i.e. Physics], in the præsent Age, especially such as affect the accommodation of Mechanick Maxims to the sensible operations of Nature, that their minds abhor the embraces of any other.'

Boyle had a great respect for Descartes, described him as 'ingenious' and 'excellent' and one 'from whom I am not forward to dissent,' and regarded Democritan atoms and Cartesian corpuscles as rivals, although he himself came to prefer the former. In his *Origin of Formes and Qualities* (1666), Boyle, partly under the influence of Descartes, gave full support to a corpuscular philosophy in explaining the properties of substances on purely mechanical grounds, and the ideas expressed in the book were well received.

Hooke, who was well acquainted with the writings of Descartes—whence, in Newton's opinion, he had derived his theory of colour—mentions Descartes several times in his *Micrographia*

(1665), and in his *Lampas* (1677) he wrote: 'Now though, I confess, I suppose Gravity to be otherwise performed than as Des Cartes has supposed, yet do I believe his Suppositions so Rational and Ingenious, and so much above the Objections brought against them, and so much better than any other I have yet met with, as no wise to deserve to be esteemed *fœda deliria*, as the learned Doctor [Henry More] is pleased to term them.' More was the Cambridge Platonist, who had called upon contemporary science to support Christianity against scepticism; later, in his *Enchiridion Metaphysicum* (1671), he renounced Cartesianism, which, with Cudworth and his fellow-Platonists, he had come to regard as mere atheism, although it was founded on a belief in the existence of God. More's criticism, after the publication of the *Origin of Formes*, had deeply disturbed Boyle, who had often emphasized the basis of Cartesianism, but a not altogether satisfactory explanation in a letter from More to Boyle, to the effect that he had written only against the materialistic aspects of the system, seems to have saved a possible breach between two friends.

Newton, it is known, read the *Géométrie* of Descartes in 1664 and devised his 'method of fluxions' in 1665; it has been held that the ideas he may have obtained from the *Géométrie* were possibly a factor in his invention of the calculus.

In his *Principia*, Newton had to deal with the vortex theory of Descartes, which, with increasing knowledge, had become accepted in place of the Aristotelian system of the world, and to its refutation he devoted most of Book II. In Proposition LII he showed that, in a vortex system, the periodic times of its different parts must be as the squares of their distances from the centre, whereas the observations summarized in Kepler's third law had shown that the squares of the periodic times of the planets were as the cubes of their distances from the Sun. However, even after the publication of the *Principia* in 1687, Cartesianism remained acceptable in many quarters, possibly because the vortex theory kept the planets rolling by contact with the ever-moving subtle fluid that filled all space, whereas Newton's system involved the incomprehensible 'action at a distance.'

The second edition of the *Principia* appeared in 1713, twenty-six years after the first. Roger Cotes, who wrote for it his well-known Preface, was still mainly concerned with the refutation of the vortex theory, the continued acceptance of which was due not only to the difficulty in Newton's system already mentioned, but to the popularity of a remarkable textbook of physics. This was the *Traité de Physique* of Jacques Rohault, which was founded on the system of Descartes and which first appeared in 1671. Latin translations were published in Geneva in 1674, and in London in 1682. Many French editions followed, and, before Newton's *Principia* appeared in 1687, the *Traité* had established itself in British universities. Later, it maintained its place even in Newton's own university of Cambridge, although the Newtonian system had been taught in Edinburgh by David Gregory before he left for Oxford in 1690, and in St. Andrews by his brother James. In Oxford, Cartesianism was still the 'New Philosophy' (as opposed to that of Aristotle) in 1693, when Addison defended it in an oration in the Sheldonian Theatre. When, however, another Latin version (1697) of Rohault's *Traité* was in course of preparation by Samuel Clarke, protests by Whiston led the translator to add notes on Newton's work to the later editions; these, in effect, contradicted the text, so that, in Playfair's words, 'the Newtonian Philosophy first entered the University of Cambridge under the protection of the Cartesian.' This new translation appeared in 1697, and later editions followed; there were also English versions in 1723, 1728–9, and 1735.

It was not until the middle of the eighteenth century that Cartesianism finally gave way to Newtonianism. Yet, while the cosmical system of Descartes was rejected, the influence of its inventor persisted in other directions throughout the eighteenth and nineteenth centuries. It persists, indeed, even now, through his belief in the existence of an objective material world, the mechanism of which it was the primary aim of science to unravel.

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What is an elementary particle?

E. SCHRÖDINGER

Increasing knowledge has in some ways made us not more certain but less certain of the nature of matter. Whereas Dalton and his school had a clear picture of the existence of atomic particles as real and indestructible solid particles, modern wave mechanics implies very clearly that, in fact, they are not identifiable individuals at all. Although Daltonian conceptions provide convenient terms in which to describe the properties of matter, their original significance has undergone very important changes during the last thirty years.

1. A PARTICLE IS NOT AN INDIVIDUAL

Atomism in its latest form is called quantum mechanics. It has extended its range to comprise, besides ordinary matter, all kinds of radiation, including light—in brief, all forms of energy, ordinary matter being one of them. In the present form of the theory the 'atoms' are electrons, protons, photons, mesons, etc. The generic name is elementary particle, or merely particle. The term atom has very wisely been retained for chemical atoms, though it has become a misnomer.

This essay deals with the elementary particle, more particularly with a certain feature that this concept has acquired—or rather lost—in quantum mechanics. I mean this: that the elementary particle is not an individual; it cannot be identified, it lacks 'sameness.' The fact is known to every physicist, but is rarely given any prominence in surveys readable by non-specialists. In technical language it is covered by saying that the particles 'obey' a new-fangled statistics, either Einstein-Bose or Fermi-Dirac statistics. The implication, far from obvious, is that the unsuspected epithet 'this' is not quite properly applicable to, say, an electron, except with caution, in a restricted sense, and sometimes not at all. My objective here is to explain this point and to give it the thought it deserves. In order to create a foil for the discussion, let me summarize in sections 2–5 what we are usually told about particles and waves in the new physics.

2. CURRENT VIEWS: THE AMALGAMATION OF PARTICLES AND WAVES

Our image of the material world had been made up of two kinds of 'fittings': waves and particles. The former were instanced mainly, if not exclusively, by Maxwell's waves of electromagnetic energy, comprising such as are used in radio, light, X-rays, and gamma-rays. Material bodies were said to consist of particles. One was also familiar with jets of particles, called corpuscular rays, such as cathode rays, beta-rays, alpha-rays, anode rays, etc. Particles would emit and absorb waves. For instance, cathode rays (electrons), when slowed down by colliding with atoms, emit X-rays. The distinction between particles and waves was, however, considered as clear-cut as that between a violin and its sound. An examinee who alleged cathode rays to be waves, or X-rays to be jets of particles, would have got very bad marks.

In the new setting of ideas the distinction has vanished, because it was discovered that all particles have also wave properties, and *vice versa.* Neither of the two concepts must be discarded, they must be amalgamated. Which aspect obtrudes itself depends not on the physical object, but on the experimental device set up to examine it. A jet of cathode rays, for example, produces in a Wilson cloud chamber discrete tracks of water droplets—curved tracks if there is a magnetic field to deflect the electrons, otherwise straight alignments of droplets. We cannot but interpret them as traces of the paths of single electrons. Yet the same jet, after crossing a narrow tube placed at right angles to it and containing crystal powder, will produce on a photographic plate at some distance behind the tube a pattern of concentric circles. This pattern can be understood in all its details when looked upon as the interference pattern of waves, and in no other way. Indeed, it bears a close resemblance to similarly produced X-ray patterns.

The suspicion arises: are the conical jets that impinge on the photographic plate and form the pattern of circles really cathode rays; are they not perhaps secondary X-rays? The suspicion has to be dismissed, for the whole system of circles can be displaced by a magnet, while X-rays can not; moreover, by putting a lead screen with a small hole in it in the place of the photographic plate, a jetlet can be isolated from one of the conical jets and made to display any of the typical particle characters of cathode rays: it will produce discrete tracks in a cloud chamber; bring about discrete discharges in a Geiger-Müller counter; and charge up a Faraday cage in which it is intercepted.

A vast amount of experimental evidence clinches the conviction that wave characteristics and particle characteristics are never encountered singly, but always in a union; they form different aspects of the same phenomenon, and indeed of all physical phenomena. The union is not a loose or superficial one. It would be quite unsatisfactory to consider cathode rays to consist both of particles and of waves. In the early days of the new theory it was suggested that the particles might be singular spots within the waves, actually singularities in the meaning of the mathematician. The white crests on a moderately rough sea would be a fairly adequate simile. The idea was very soon abandoned. It seems that both concepts, that of waves and that of particles, have to be modified considerably, so as to attain a true amalgamation.

3. CURRENT VIEWS: THE NATURE OF WAVES

The waves, so we are told, must not be regarded as quite real waves. It is true that they produce interference patterns—which is the crucial test that in the case of light had removed all doubts as to the reality of the waves. However, we are now told that all waves, including light, ought rather to be looked upon as 'probability waves.' They are only a mathematical device for computing the probability of finding a particle in certain conditions, for instance (in the above example), the probability of an electron hitting the photographic plate within a small specified area. There it is registered by acting on a grain of silver bromide. The interference pattern is to be regarded as a statistical registration of the impinging electrons. The waves are in this context sometimes referred to as guiding waves—guiding or directing the particles on their paths. The guidance is not to be regarded as a rigid one; it merely constitutes a probability. The clear-cut pattern is a statistical result, its definiteness being due to the enormous number of particles.

Here I cannot refrain from mentioning an objection which is too obvious not to occur to the reader. Something that influences the physical behaviour of something else must not in any respect be called less real than the something it influences—whatever meaning we may give to the dangerous epithet 'real.' It is certainly useful to recall at times that all quantitative models or images conceived by the physicist are, epistemologically, only mathematical devices for computing observable events, but I cannot see that this applies more to, say, light-waves than to, say, oxygen molecules.

4. CURRENT VIEWS: THE NATURE OF PARTICLES (UNCERTAINTY RELATION)

As regards the modification required in the concept of a particle, the stress is on Heisenberg's uncertainty relation. The so-called classical mechanics hinged on Galileo's and Newton's discovery that the thing which in a moving body is determined at any instant by the other bodies in its environment is only and precisely its acceleration, or, in mathematical terms, the second derivatives with respect to time of the co-ordinates. The first derivatives, commonly called the velocity, are therefore to be included in the description of the momentary state of the body, together with the co-ordinates themselves which label its momentary place in space or 'whereness' (or ubiety, to use an antiquated but convenient word). Thus, to describe the momentary state of a particle, two independent data were required: its co-ordinates and their first time derivatives, or ubiety and velocity. According to the new theory less is required, and less is obtainable. Either of the two data can be given with arbitrary accuracy, provided that no store is set on the other, but both cannot be known together with absolute precision. One may not even conceive of both as having absolutely sharp values at the same instant. They mutually blur each other, as it were. Broadly speaking, the product of the latitudes of their respective inaccuracies cannot be reduced below a fixed constant. For an electron, this constant happens to be about 1 if the units centimetre and second are used. Thus, if the velocity of an electron is considered sharp with a latitude of only 1 cm/sec, its location has to be considered as blurred within the latitude of 1 cm. The strangeness does not lie in the mere existence of inaccuracies, for the particle might be a thing of vague and changeable extension, within which slightly different velocities prevailed at different spots. Then, however, a sharp location or ubiety would probably entail a sharply defined velocity and *vice versa*. Actually it is just the other way round.

5. CURRENT VIEWS: THE MEANING OF THE UNCERTAINTY RELATION

Two links connect this strange and certainly very fundamental statement to other parts of the theory. It can be arrived at by declaring that a particle is equivalent to its guiding wave, and has no characteristics save those indicated by the guiding wave according to a certain code. The code is simple enough. The ubiety is indicated by the extension of the wave, the latitude in the velocity by the range of wave numbers. 'Wave number' is short for reciprocal of the wavelength. Each wave number corresponds to a certain velocity proportional to it. That is the code. It is a mathematical truism that the smaller a wave group, the wider is the (minimum) spread of its wave numbers.

Alternatively, we may scrutinize the experimental procedure for determining either the ubiety or the velocity. Any such measuring device implies a transfer of energy between the particle and some measuring instrument—eventually the observer himself, who has to take a reading. This means an actual physical interference with the particle. The disturbance cannot be arbitrarily reduced, because energy is not exchanged continuously but in portions. We are given to understand that, when measuring one of the two items, ubiety or velocity, we interfere with the other the more violently the higher the precision we aim at. We blur its value within a latitude inversely proportional to the latitude of error allowed in the first.

In both explanations the wording seems to suggest that the uncertainty or lack of precision refers to the attainable knowledge about a particle rather than to its nature. Indeed, by saying that we disturb or change a measurable physical quantity we logically imply that it has certain values before and after our interference, whether we know them or not. And in the first explanation, involving the wave, if we call it a guiding wave how should it guide the particle on its path, if the particle has not got a path? If we say the wave indicates the probability of finding the particle at A, or at B, or at C . . . this seems to imply that the particle is at one, and one only, of these places; and similarly for the velocity. (Actually the wave does indicate both probabilities simultaneously, one by its extension, the other by its wave numbers.) However, the current view does not accept either ubiety or velocity as permanent objective realities. It stresses the word 'finding.' Finding the particle at point A does not imply that it has been there before. We are more or less given to understand that our measuring device has brought it there or 'concentrated' it at that point, while at the same time we have disturbed its velocity. And this does not imply that the velocity 'had' a value. We have only disturbed or changed the probability of finding this or that value of the velocity if we measure it. The implications as to 'being' or 'having' are misconceptions, to be blamed on language. Positivist philosophy is invoked to tell us that we must not distinguish between the knowledge we can obtain of a physical object and its actual state. The two are one.

6. CRITICISM OF THE UNCERTAINTY RELATION

I will not discuss here that tenet of positivist philosophy. I fully agree that the uncertainty relation has nothing to do with incomplete knowledge. It does reduce the amount of information attainable about a particle as compared with views held previously. The conclusion is that these views were wrong and we must give them up. We must not believe that the completer description they demanded about what is really going on in the physical world is conceivable, but in practice unobtainable. This would mean clinging to the old view. Still, it does not necessarily follow that we must give up speaking and thinking in terms of what is really going on in the physical world. It has become a convenient habit to picture it as a reality. In everyday life we all follow this habit, even those philosophers who opposed it theoretically, such as Bishop Berkeley. Such theoretical controversy is on a different plane. Physics has nothing to do with it. Physics takes its start from everyday experience, which it continues by more subtle means. It remains akin to it, does not transcend it generically, it cannot enter into another realm. Discoveries in physics cannot in themselves—so I believe—have the authority of forcing us to put an end to the habit of picturing the physical world as a reality.

I believe the situation is this. We have taken over from previous theory the idea of a particle and all the technical language concerning it. This idea is inadequate. It constantly drives our mind to ask for information which has obviously no significance. Its imaginative structure exhibits features which are alien to the real particle. An adequate picture must not trouble us with this disquieting urge; it must be incapable of picturing more than there is; it must refuse any further addition. Most people seem to think that no such picture can be found. One may, of course, point to the circumstantial evidence (which I am sorry to say is not changed by this essay) that in fact none has been found. I can, however, think of some reasons for this, apart from the genuine intricacy of the case. The palliative, taken from positivist philosophy and purporting to be a reasonable way out, was administered fairly early and authoritatively. It seemed to relieve us from the search for what I should call real understanding; it even rendered the endeavour suspect, as betraying an unphilosophical mind—the mind of a child who regretted the loss of its favourite toy (the picture or model) and would not realize that it was gone for ever. As a second point, I submit that the difficulty may be intimately connected with the principal subject of this paper, to which I shall now turn without further delay. The uncertainty relation refers to the particle. The particle, as we shall see, is not an identifiable individual. It may indeed well be that no individual entity can be conceived which would answer the requirements of the adequate picture stated above.

It is not at all easy to realize this lack of individuality and to find words for it. A symptom is that the probability interpretation, unless it is expressed in the most highly technical language of mathematics, seems to be vague as to whether the wave gives information about one particle or about an *ensemble* of particles. It is not always quite clear whether it indicates the probability of finding 'the' particle or of finding 'a' particle, or indicates the likely or average number of particles in, say, a given small volume. Moreover the most popular view on probability tends to obliterate these differences. It is true that exact mathematical tools are available to distinguish between them. A point of general interest is involved, which I will explain. A method of dealing with the problem of many particles was indicated in 1926 by the present writer. The method uses waves in many-dimensional space, in a manifold of $3N$ dimensions, N being the number of particles. Deeper insight led to its improvement. The step leading to this improvement is of momentous significance. The many-dimensional treatment has been superseded by so-called second quantization, which is mathematically equivalent to uniting into one three-dimensional formulation the cases $N = 0, 1, 2, 3 \ldots$ (to infinity) of the many-dimensional treatment. This highly ingenious device includes the so-called new statistics, with which we shall have to deal below in much simpler terms. It is the only precise formulation of the views now held, and the one that is always used. What is so very significant in our present context is that one cannot avoid leaving indeterminate the number of the particles dealt with. It is thus obvious that they are not individuals.

7. THE NOTION OF A PIECE OF MATTER

I wish to set forth a view on matter and the material universe, to which Ernst Mach [1], Bertrand Russell [2], and others were led by a careful analysis of concepts. It differs from the popular view. We are, however, not concerned with the psychological origin of the concept of matter but with its epistemological analysis. The attitude is so simple that it can hardly claim complete novelty; some pre-Socratics, including the materialist Democritus [3], were nearer to it than were the great men who resuscitated science and moulded it during the seventeenth to nineteenth centuries.

According to this view, a piece of matter is the name we give to a continuous string of events that succeed each other in time, immediately successive ones being as a rule closely similar. The single event is an inextricable complex of sensates, of associated memory images, and of expectations associated with the former two. The sensates prevail in the case of an unknown object, say a distant white patch on the road, which might be a stone, snow, salt, a cat or a dog, a white shirt or blouse, a handkerchief. Even so, within the ensuing string of events we usually know from general experience how to discount the changes caused by motions of our own body, in particular of our direction of sight. As soon as the nature of the object is recognized, images and expectations begin to prevail. The latter concern sensations as hard, soft, heavy, flexible, rough, smooth, cold, salty, etc., associated with the image of touching and handling; they also concern spontaneous movements or noises such as barking, mewing, shouting, etc. It should be noted that I am not speaking of our thoughts or considerations about the object, but of what forms part and parcel of our perception of it—of what it is to us. However, the limit is not sharp. As our familiarity with a piece of matter grows, and in particular as we approach its scientific aspect, the range of expectations in regard to it widens, eventually to include all the information science has ascertained, e.g. melting point, solubility, electric conductivity, density, chemical and crystalline structure, and so on. At the same time, the momentary sensational core recedes in relevance the more the object becomes familiar to us, whether by scientific knowledge or by everyday use.

8. INDIVIDUALITY OR 'SAMENESS'

After a certain wealth of association has come to outshine the core of sensates, the latter is no longer needed to keep the complex together. It persists even when the contact of our senses with the object temporarily ceases. And more than that: the complex is latently conserved even when the whole string is interrupted by our turning away from the object to others and forgetting all about it. Indeed, this is not exceptional, but a rule which—since we sometimes sleep—has no exception. But we have adopted the useful device of filling these gaps. We supplement the missing parts of the strings relating to pieces of matter in our nearer and farther surroundings, to cover the periods when we neither watch them nor think of them. When a familiar object re-enters our ken, it is usually recognized as a continuation of previous appearances, as being the same thing. The relative permanence of individual pieces of matter is the most momentous feature of both everyday life and scientific experience. If a familiar article, say an earthenware jug, disappears from your room, you are quite sure somebody must have taken it away. If after a time it reappears, you may doubt whether it really is the same one—breakable objects in such circumstances are often not. You may not be able to decide the issue, but you will have no doubt that the doubtful sameness has an indisputable meaning—that there is an unambiguous answer to your query. So firm is our belief in the continuity of the unobserved parts of the strings!

No doubt the notion of individuality of pieces of matter dates from time immemorial. I suppose animals must have it in some way, and a dog, when seeking for his ball that has been hidden, displays it very plainly. Science has taken it over as a matter of course. It has refined it so as safely to embrace all cases of apparent disappearance of matter. The idea that a log which burns away first turns into fire, then into ashes and smoke, is not alien to the primitive mind. Science has substantiated it; though the appearance in bulk may change, the ultimate constituents of the matter do not. This was (in spite of his occasional scepticism mentioned above) the teaching of Democritus. Neither he nor Dalton doubted that an atom which was originally present in the block of wood is afterwards either in the ashes or in the smoke.

9. THE BEARING ON ATOMISM

In the new turn of atomism that began with the papers of Heisenberg and of de Broglie in 1925 such an attitude has to be abandoned. This is the most startling revelation emerging from the ensuing development, and the feature which in the long run is bound to have the most important consequences. If we wish to retain atomism we are forced by observed facts to deny the ultimate constituents of matter the character of identifiable individuals. Up to recently, atomists of all ages, for all I know, had transferred that characteristic from visible and palpable pieces of matter to the atoms, which they could not see or touch or observe singly. Now we do observe single particles; we see their tracks in the cloud chamber and in photographic emulsions; we register the practically simultaneous discharges caused by a single swift particle in two or three Geiger counters placed at several yards' distance from each other. Yet we must deny the particle the dignity of being an absolutely identifiable individual. Formerly, if a physicist were asked what stuff the atoms themselves were made of, he might smile and shirk the answer. If the inquirer insisted on the question whether he might imagine them as small unchangeable bits of ordinary matter, he would get the smiling reply that there was no point in doing so but that it would do no harm. The formerly meaningless question has now gained significance. The answer is definitely in the negative. An atom lacks the most primitive property we associate with a piece of matter in ordinary life. Some philosophers of the past, if the case could be put to them, would say that the modern atom consists of no stuff at all but is pure shape.

10. THE MEANING OF THE NEW STATISTICS

We must at last proceed to give the reasons for this change of attitude in a more comprehensible form than at the end of section 6. It rests on the so-called new statistics. There are two of them. One is the Bose-Einstein statistics, whose novelty and relevance were first stressed by Einstein. The other is the Fermi-Dirac statistics, of which the most pregnant expression is Pauli's exclusion principle. I shall try to explain the new statistics, and its relation to the old classical or Boltzmann statistics, to those who have never heard about such things and perhaps may be puzzled by what 'statistics' means in this context. I shall use an instance from everyday life. It may seem childishly simple, particularly because we have to choose small numbers—actually 2 and 3—in order to make the arithmetic surveyable. Apart from this, the illustration is completely adequate and covers the actual situation.

Three schoolboys, Tom, Dick, and Harry, deserve a reward. The teacher has two rewards to distribute among them. Before doing so, he wishes to realize for himself how many different distributions are at all possible. This is the only question we investigate (we are not interested in his eventual decision). It is a statistical question: to count the number of different distributions. The point is that the answer depends on the nature of the rewards. Three different kinds of reward will illustrate the three kinds of statistics.

(*a*) The two rewards are two memorial coins with portraits of Newton and Shakespeare respectively. The teacher may give Newton either to Tom or to Dick or to Harry, and Shakespeare either to Tom or to Dick or to Harry. Thus there are three times three, that is nine, different distributions (classical statistics).

(*b*) The two rewards are two shilling-pieces (which, for our purpose, we must regard as indivisible quantities). They can be given to two different boys, the third going without. In addition to these three possibilities there are three more: either Tom or Dick or Harry receives two shillings. Thus there are six different distributions (Bose-Einstein statistics).

(*c*) The two rewards are two vacancies in the football team that is to play for the school. In this case two boys can join the team, and one of the three is left out. Thus there are three different distributions (Fermi-Dirac statistics).

Let me mention right away: the *rewards* represent the particles, two of the same kind in every case; the boys represent states the particle can assume. Thus, 'Newton is given to Dick' means: the particle Newton takes on the state Dick.

Notice that the counting is natural, logical, and indisputable in every case. It is uniquely determined by the nature of the objects: memorial coins, shillings, memberships. They are of different categories. Memorial coins are individuals distinguished from one another. Shillings, for all intents and purposes, are not, but they are still capable of being owned in the plural. It makes a difference whether you have one shilling, or two, or three. There is no point in two boys exchanging their shillings. It does change the situation, however, if one boy gives up his shilling to another. With memberships, neither has a meaning. You can either belong to a team or not. You cannot belong to it twice over.

Experimental evidence proves that statistical counts referring to elementary particles must never follow the pattern (*a*), but must follow either (*b*) or (*c*). Some hold that for all genuinely elementary particles (*c*) is competent. Such particles, electrons for instance, correspond to membership in a club; I mean to the abstract notion of membership, not to the members. Any person eligible to membership in that club represents a well-defined state an electron can take on. If the person is a member, that means there is an electron in that particular state. According to Pauli's exclusion principle, there can never be more than one electron in a particular state. Our simile renders this by declaring double membership meaningless—as in most clubs it would be. In the course of time the list of members changes, and membership is now attached to other persons: the electrons have gone over into other states. Whether you can, in a loose way, speak of a certain membership going over from Dick to Tom, thence from Tom to Harry, etc., depends on the circumstances. They may suggest this view, or they may not, but never in an absolute fashion. In this our simile is perfect, for it is the same with an electron. Moreover, it is quite appropriate to consider the number of members as fluctuating. Indeed, electrons too are created and annihilated.

The example may seem odd and inverted. One might think, 'Why cannot the people be the electrons and various clubs their states? That would be so much more natural.' The physicist regrets, but he cannot oblige. And this is just the salient point: the actual statistical behaviour of electrons cannot be illustrated by any simile that represents them by identifiable things. That is why it follows from their actual statistical behaviour that they are not identifiable things.

The case (*b*), illustrating Einstein-Bose statistics, is competent for light quanta (photons), *inter alia.* It hardly needs discussion. It does not strike us as so strange for the very reason that it includes light, i.e. electro-magnetic energy; and energy, in pre-quantum times, had always been thought of in very much the way our simile represents it, viz. as having quantity, but no individuality.

11. RESTRICTED NOTION OF IDENTITY

The most delicate question is that of the states of, say, an electron. They are, of course, to be defined not classically, but in the light of the uncertainty relation. The rigorous treatment referred to at the end of section 6 is not really based on the notion of 'state of one electron' but on that of 'state of the assembly of electrons.' The whole list of members of the club, as it were, has to be envisaged together—or rather several membership lists, corresponding to the several kinds of particles that go to compose the physical system under consideration. I mention this, not to go into details about it, but because, taken rigorously, the club simile has two flaws. First, the possible states of an electron (which we had assimilated to the persons eligible for membership) are not absolutely defined; they depend on the arrangement of the—actual or imagined—experiment. Given this arrangement, the states are well-defined individuals, which the electrons are not. They also form—and this is the second flaw of the simile—a well-ordered manifold. That is, there is a meaning in speaking of neighbouring states as against such as are farther remote from each other. Moreover, I believe it is true to say that this order can be conceived in such a fashion that, as a rule, whenever one occupied state ceases to be occupied, a neighbouring state becomes occupied.

This explains that, in favourable circumstances, long strings of successively occupied states may be produced, similar to those contemplated in sections 7 and 8. Such a string gives the impression of an identifiable individual, just as in the case of any object in our daily surrounding. It is in this way that we must look upon the tracks in the cloud chamber or in a photographic emulsion, and on the (practically) simultaneous discharges of Geiger counters set in a line, which discharges we say are caused by the same particle passing one counter after another. In such cases it would be extremely inconvenient to discard this terminology. There is, indeed, no reason to ban it, provided we are aware that, on sober experimental grounds, the sameness of a particle is not an absolute concept. It has only a restricted significance and breaks down completely in some cases.

In what circumstances this restricted sameness will manifest itself is fairly obvious: namely, when only few states are occupied in the region of the state-manifold with which we are concerned, or, in other words, when the occupied states are not too crowded in that region, or when occupation is a rare event—the terms few, crowded, and rare all referring to the state-manifold. Otherwise, the strings intermingle inextricably and reveal the true situation. In the last section we shall formulate the quantitative condition for the prevailing of restricted individuality. Now we ask what happens when it is obliterated.

12. CROWDEDNESS AND WAVE ASPECT

One gains the impression that according as the individuality of the particles is wiped out by crowding, the particle aspect becomes altogether less and less expedient and has to be replaced by the wave aspect. For instance, in the electronic shell of an atom or molecule the crowding is extreme, almost all the states within a certain region being occupied by electrons. The same holds for the so-called free electrons inside a metal. Indeed, in both cases the particle aspect becomes entirely incompetent. On the other hand, in an ordinary gas the molecules are extremely rare in the wide region of states over which they spread. No more than one state in 10,000 or so is occupied. And, indeed, the theory of gases, based on the particle aspect, was able to attain great perfection long before the wave nature of ordinary matter was discovered. (In the last remark I have been speaking of the molecules as if they were ultimate particles; this is legitimate as far as their translatory motion is concerned.)

It is tempting to assign to the two rivals, the particle aspect and the wave aspect, full competences in the limiting cases of extreme 'rarefaction' and extreme 'crowding' respectively. This would separate them, as it were, with only some sort of transition required for the intermediate region. This idea is not entirely wrong, but it is also far from correct. One may remember the interference patterns referred to in section 2 in evidence of the wave nature of the electron. They can be obtained with an arbitrarily faint bundle of cathode rays, provided the exposure is prolonged. Thus a typical wave phenomenon is produced here, irrespective of crowding. Another instance is this. A competent theoretical investigation of the collision of two particles, whether of the same or of different kind, has to take account of their wave nature. The results are duly applied to the collisions of cosmic ray particles with atomic nuclei in the atmosphere, both being extremely rarefied in every sense of the word. But perhaps this is trivial; it only means that even an isolated particle, which gives us the illusion of transitory individuality, must yet not be likened to a classical particle. It remains subject to the uncertainty relation, of which the only tolerable image is the guiding wave group.

13. THE CONDITION FOR THE PARTICLE ASPECT

The following is the quantitative condition for strings to develop which counterfeit individuals and suggest the particle aspect: the product of the momentum p and the average distance l between neighbouring particles must be fairly large compared with Planck's constant h; thus

$$pl >> h.$$

(The momentum p—and not the velocity—is the thing we should really have referred to when, in sections 4 and 5, we dealt with the uncertainty relation; p is simply the product of the mass and the velocity, unless the latter is comparable with that of light.)

A large l means a low density in ordinary space. What matters, however, is the density in the manifold of states—or phase space, to use the technical term. That is why the momentum p comes in. It is gratifying to remember that those very obvious strings—visible tracks in the cloud chamber or in the photographic emulsion, and simultaneous discharges of aligned counters—are all produced by particles with comparatively very large momentum.

The above relation is familiar from the theory of gases, where it expresses the condition which must be fulfilled in very good approximation in order that the old classical particle theory of gases should apply in very good approximation. This theory has to be modified according to quantum theory when the temperature is very low and at the same time the density very high, so that the product pl is no longer very large compared with h. This modification is called the theory of degenerate gases, of which the most famous application is that by A. Sommerfeld to the electrons inside a metal; we have mentioned them before as an instance of extreme crowding.

There is the following connection between our relation and the uncertainty relation. The latter allows one at any moment to distinguish a particle from its neighbours by locating it with an error considerably smaller than the average distance l. But this entails an uncertainty in p. On account of it, as the particle moves on, the uncertainty in the location grows. If one demands that it still remain well below l after the particle has covered the distance l, one arrives precisely at the above relation.

But again I must warn of a misconception which the preceding sentences might suggest, viz. that crowding only prevents us from registering the identity of a particle, and that we mistake one particle for the other. The point is that they are not individuals which could be confused or mistaken one for another. Such statements are meaningless.

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[2] RUSSELL, BERTRAND. 'Human Knowledge, Its Scope and Limits,' Allen and Unwin, London. 1948.

[3] DIELS, HERMANN. 'Die Fragmente der Vorsokratiker,' Weidmannsche Buchhandlung, Berlin. 1903. (The reference is mainly to the fragment 125 of Democritus.)

SIXTH INTERNATIONAL CONGRESS FOR THE HISTORY OF SCIENCE

The Sixth International Congress for the History of Science, and the Twelfth Congress of the International Society for the History of Medicine, will be held at Amsterdam on 14th to 21st August, 1950. It is being organized by the *Genootschap voor Geschiedenis der Geneeskunde, Wiskunde en Natuurwetenschappen* at Leiden, under the auspices of the International Academy and the International Union for the History of Science.

There will be five sections of the Congress, viz. (i) history of mathematics, physics, astronomy, geography, and geology; (ii) history of chemistry, mineralogy, pharmacy, and biology; (iii) history of applied science and technology; (iv) history of medicine; and (v) general problems, methods, and philosophy of science. The fourth section is at the same time the XIIth Congress of the *Société Internationale d'Histoire de la Médecine.*

It is intended to publish the 'Transactions of the Amsterdam Congress' in one volume in the course of 1951. Part of the communications will appear earlier in the *Archives Internationales d'Histoire des Sciences*, as was the case with the papers presented at the Lausanne Congress of 1947.

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Thomas Wright of Durham

F. A. PANETH

Although Thomas Wright's work does not place him on the same plane as such famous astronomers as Copernicus or Newton, it certainly entitles him to greater appreciation than he is generally accorded. In particular he was the first to explain, in his *Original Theory*, published in 1750, that the density of stars in the Milky Way was apparent rather than real. In postulating a disk-like shape of the stellar system he anticipated Herschel by 35 years.

Two hundred years ago, in 1750, Thomas Wright's *Original Theory or New Hypothesis of the Universe* was published in London. It was printed with the help of subscriptions, mainly from high society, and did not interest any English astronomer.

In 1837 a second edition was prepared in the United States by the well-known naturalist C. S. Rafinesque. He wrote in the 'Preface of the American Editor': 'Our worthy Author has met with total neglect at the hands of his blinded countrymen. We have not yet found him quoted anywhere, and a Philosopher and Astronomer, equal to Plato, Copernic, Newton and Herschel, was to this day nearly unknown, until we found his work, and determined at once to restore him to life and fame.'

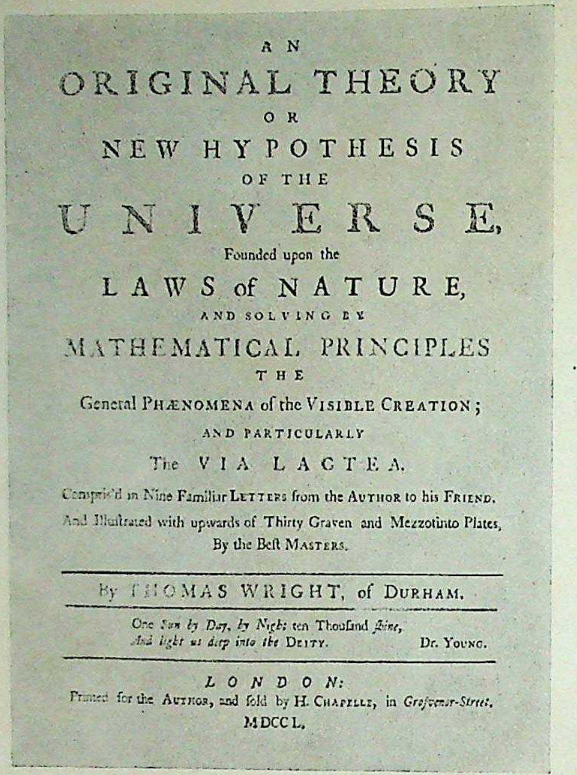
Rafinesque was right that in England Thomas Wright was completely forgotten. He was mistaken in the hope that his own effort would bring fame to him (his inconspicuous little brochure, published in Philadelphia without any plates, is today of greater rarity than Wright's impressive volume—at least in England, where the British Museum seems to possess the only copy). Rafinesque was carried too far by his enthusiasm in putting Thomas Wright on a level with the greatest names in astronomy; and he did not know that, long before his days, some of Wright's ideas had induced Immanuel Kant to compose in his East Prussian solitude his own theory of the universe, in which he gives full credit to the inspiration received from Wright.

It is due to Kant, and not to Rafinesque, that Wright's name is not forgotten. From Kant's work the astronomers Arago in Paris and Struve in St. Petersburg learned of him, and in 1848 their references prompted the London mathematician De Morgan to publish abstracts from his book and to 'submit that his name ought to be enrolled in the list of discoverers' [3]. De Morgan's perspective is distorted by his ignorance of Kant's writings, but the relationship between the two thinkers was discussed more fully in 1896 by the Durham professor of mathematics R. A. Sampson [4], in 1900 by the Glasgow professor of divinity W. Hastie [5], and more recently (in 1941) in an article in *The Durham University Journal* which was reprinted in the periodical *The Observatory* [6].

The aim of the present publication is to draw attention to the bicentenary of Thomas Wright's principal work, and to supplement all that has previously been written about him by the inclusion of illustrations taken from his book.

Thomas Wright was not only a scientist but also an artist, or at least a craftsman skilled in designing and engraving. He was not a good writer, and quotations from the printed text, without the pictures, can give no true impression of the character of his books. Two years before the appearance of his *Original Theory* he published a description of Irish antiquities in a richly illustrated book *Louthiana*, the fruit of extended studies in that part of Ireland. The two works differ so much in character that in Allibone's *Dictionary of English Literature* they are ascribed to two different authors, both of the name of Thomas Wright. They have, however, the common feature of containing very carefully executed etchings, made either by Wright himself or drawn under his close supervision. He also enjoyed some reputation as an architect; few of the thousands of visitors to Durham Cathedral are aware that the battlements on the western towers were rebuilt early in the nineteenth century after a design by Thomas Wright. His own sketch is still preserved in the library of the Durham Chapter.

The title page of his *Original Theory* indicates that he considered his explanation of the Milky Way as the most important part (see figure 1), but only two of the thirty-two full-size plates included in the book are directly connected with this subject. The first is a representation of the



AN
ORIGINAL THEORY
OR
NEW HYPOTHESIS
OF THE
UNIVERSE,
Founded upon the
LAWS of NATURE,
AND SOLVING BY
MATHEMATICAL PRINCIPLES
THE
General PHÆNOMENA of the VISIBLE CREATION;
AND PARTICULARLY
The VIA LACTEA.
Compris'd in Nine Familiar LETTERS from the AUTHOR to his FRIEND.
And Illuſtrated with upwards of Thirty Graven and Mezzotinto Plates,
By the Beſt MASTERS.

By THOMAS WRIGHT, of DURHAM.

One Sun by Day, by Night ten Thouſand ſhine,
And light us deep into the DEITY. Dr. YOUNG.

LONDON:
Printed for the AUTHOR, and ſold by H. CHAPELLE, in *Groſvenor-Street.*
MDCCL.

FIGURE 1 – *Title Page of the* Original Theory.

Milky Way as seen through a telescope (see figure 5). Today we are spoilt by the wealth and beauty of photographic illustrations in popular scientific works, but it is unlikely that before Wright such fine pictures had ever been added to an astronomical treatise. Two other mezzotint plates of equal excellence show the Pleiades (see figure 6) and a cluster in Perseus.

The second plate devoted to the Milky Way is a diagram (see figure 8), as are most of the illustrations in the *Original Theory*. In this one, Wright demonstrates why, in his opinion, the phenomenon of the Milky Way is not due to any crowding together of stars in a belt surrounding the Sun, but is only an optical effect, originating from the peculiar shape of the star system to which our sun belongs. Assuming it to be much more extended in two dimensions of space than in the third, he could easily prove that, if we are placed somewhere near the middle, the stars must appear to us in greater density, roughly in a circle, although the average distance between them may be everywhere the same. This circle is the Galaxy.

Thomas Wright was certainly entitled to call this an 'original theory.' Astronomers had just started to prove by telescopic observation that the Milky Way actually consisted not of a nebulous mass but of a great number of stars, too numerous to be seen distinctly by the naked eye, but it was entirely new to consider this high concentration of stars as only apparent, owing to the peculiar situation of the Sun relative to the other stars in our part of the universe. Thirty-five years later Herschel, on the basis of his observations, and quite in ignorance of Thomas Wright's ideas, came to the conclusion that the stars 'in our nebula' were arranged in the form of a disk, and since his days much work has been done to define the exact shape of this disk and the place of the Sun therein. The essential correctness of Herschel's view is today beyond doubt, and it is fundamentally the same as that taken by Wright in his *Original Theory*.

Kant never saw a copy of Wright's book. All his knowledge of it came from a short though very competent abstract in a Hamburg periodical which he happened to read. He accepted Wright's explanation of the Milky Way but considered it only as a remark which Wright himself 'had not used for any very important purpose, and the useful application of which he had not sufficiently observed.' Wright's conception is a geometrical one, and correct as far as it goes. Kant's is dynamical and evolutionary; on the basis of the law of universal gravitation he tries to explain the way in which the universe developed from an initial uniform distribution of particles. The title he gave to his book, *Allgemeine Naturgeschichte und Theorie des Himmels*, indicated that he was outlining the history of the world; it might be translated as 'Universal Theory of Celestial Evolution,' an aim far beyond anything that Wright attempted.

This is not the place to discuss in detail the relation of Kant's system of the world to that of Thomas Wright. One basic difference, however, might be mentioned, as it has apparently not been noticed before. Wright's conception of the universe can be seen from several of his plates (see figures 7 and 9). The many star systems he assumed to exist are always depicted as enclosed by spheres or, in cross-section, by circles (in the latter case the 'eye of providence' may be discerned in the centre of each), and many readers may have wondered what he meant by these boundaries of the star systems. No explanation is given in the *Original Theory*, but he drew a similar diagram for an earlier work, *The Use of the Globes*, and here he stated that his scheme was 'founded upon This Hypothesis, That the Stars are so many Suns; that each of these Stars or Suns is attended, (as ours is), by a proper number

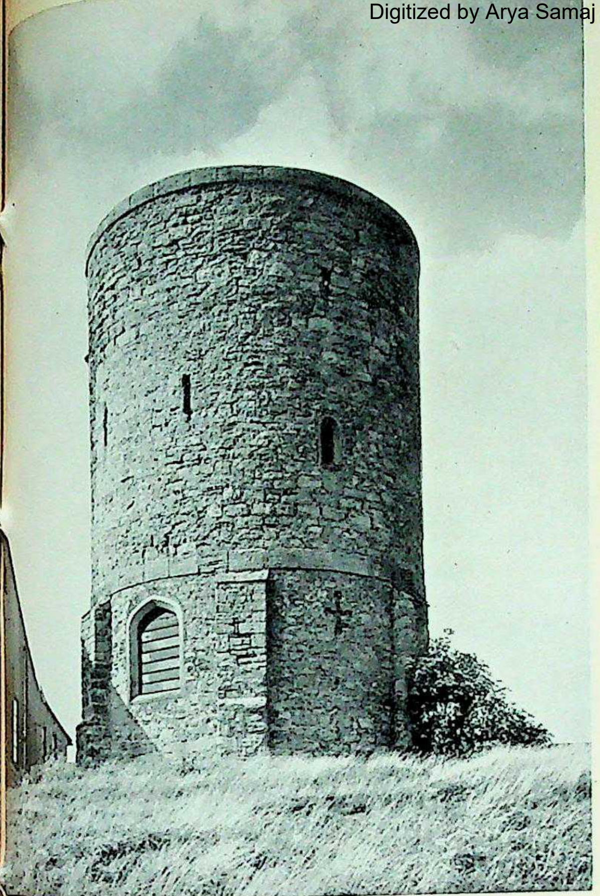


FIGURE 2 – *Westerton Folly, which Wright built, and proposed to fit up as a private observatory.*

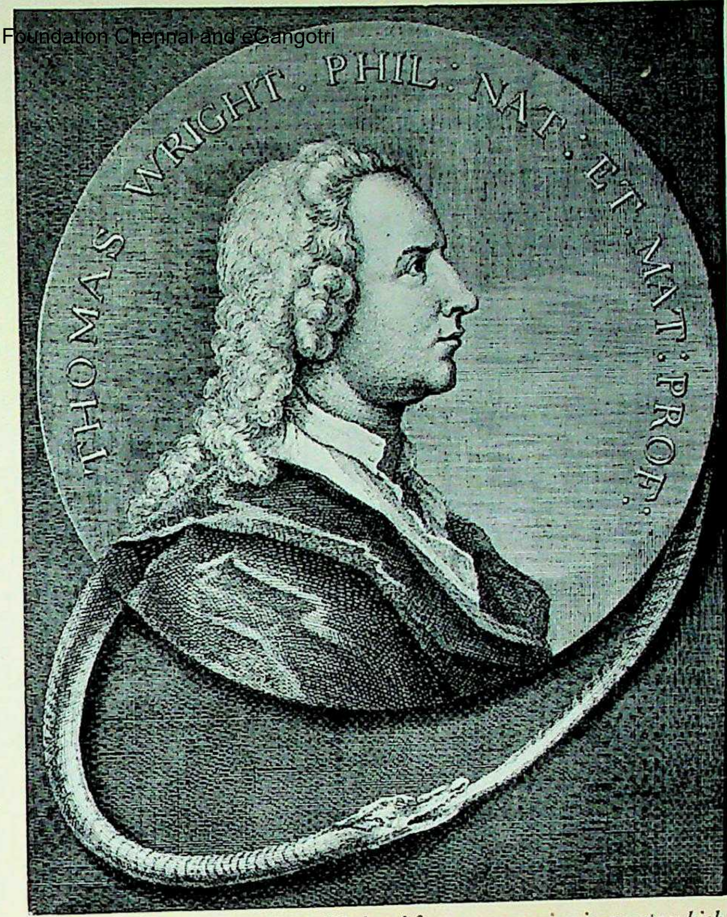

THOMAS WRIGHT. PHIL: NAT: ET MAT: PROF:

FIGURE 3 – *Thomas Wright. (Reduced from an engraving in quarto which is prefixed to a few copies of* Clavis Coelestis *and of the* Original Theory.)

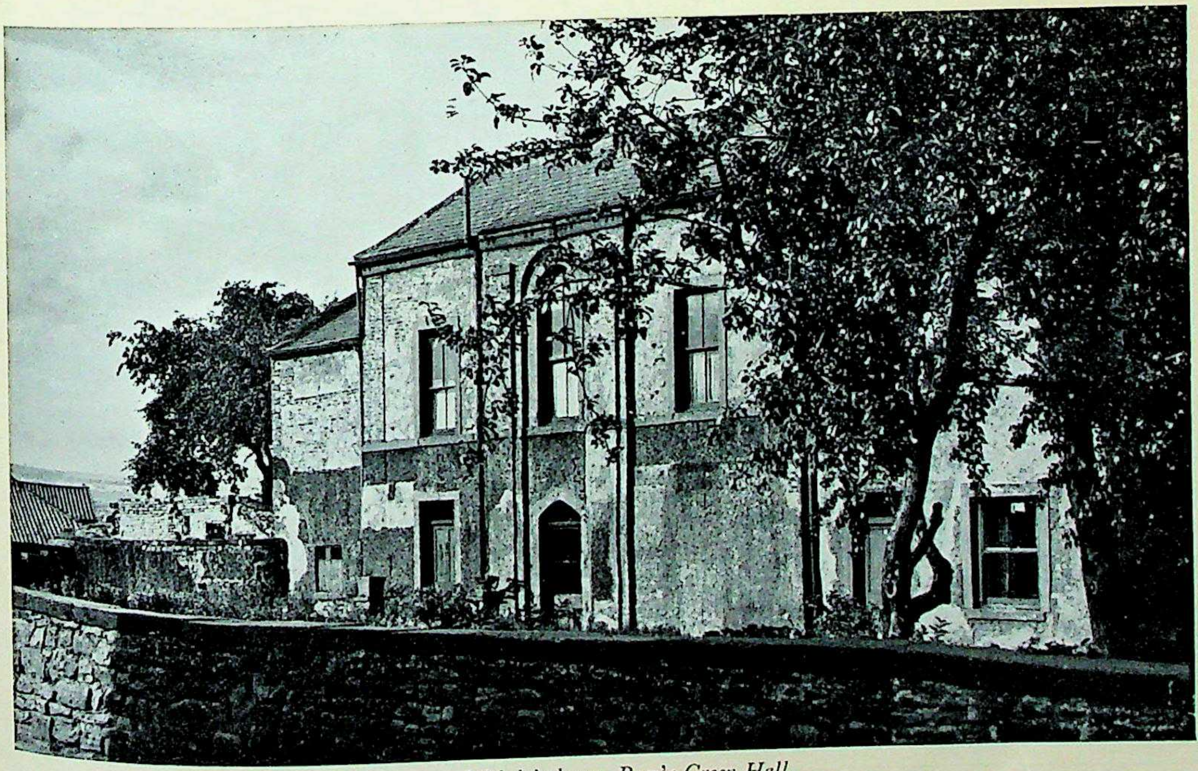


FIGURE 4 – *Wright's home, Byer's Green Hall.*

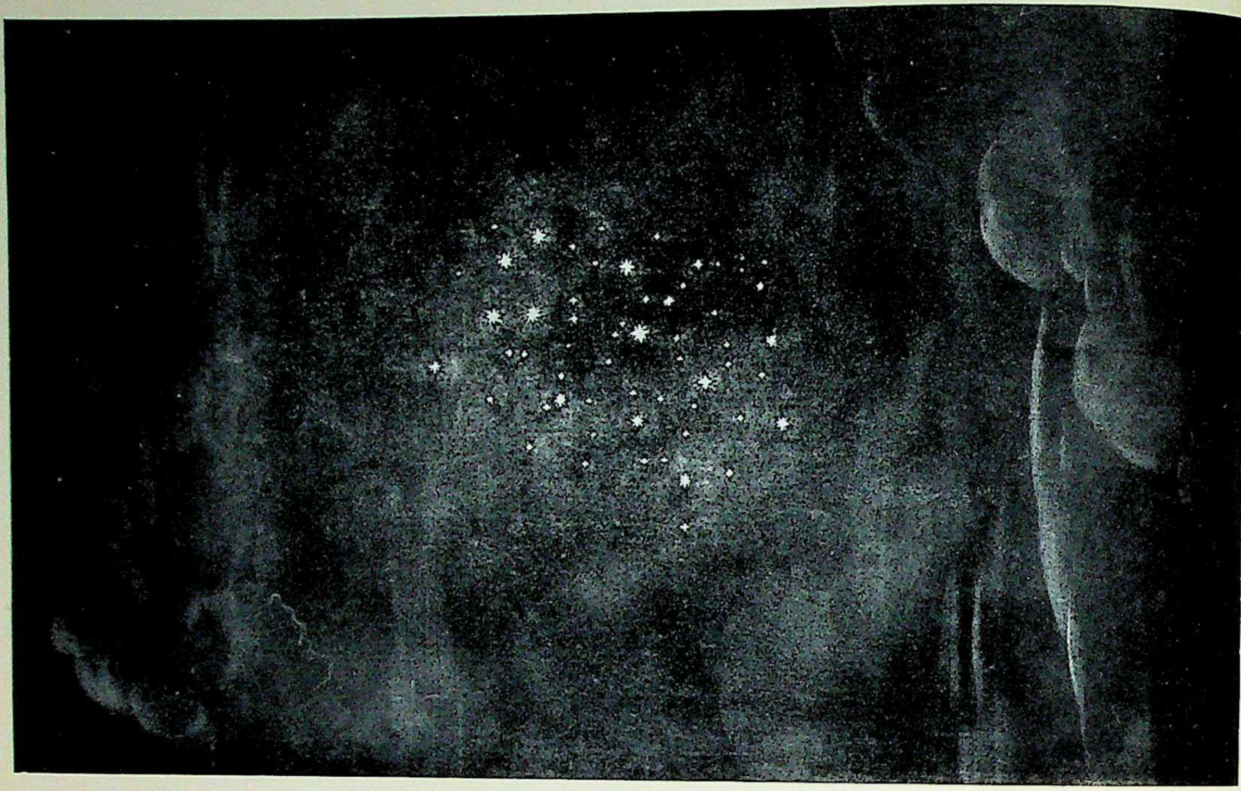


FIGURE 6–*The Pleiades, as seen 'thro' a one Foot reflecting Telescope.'*

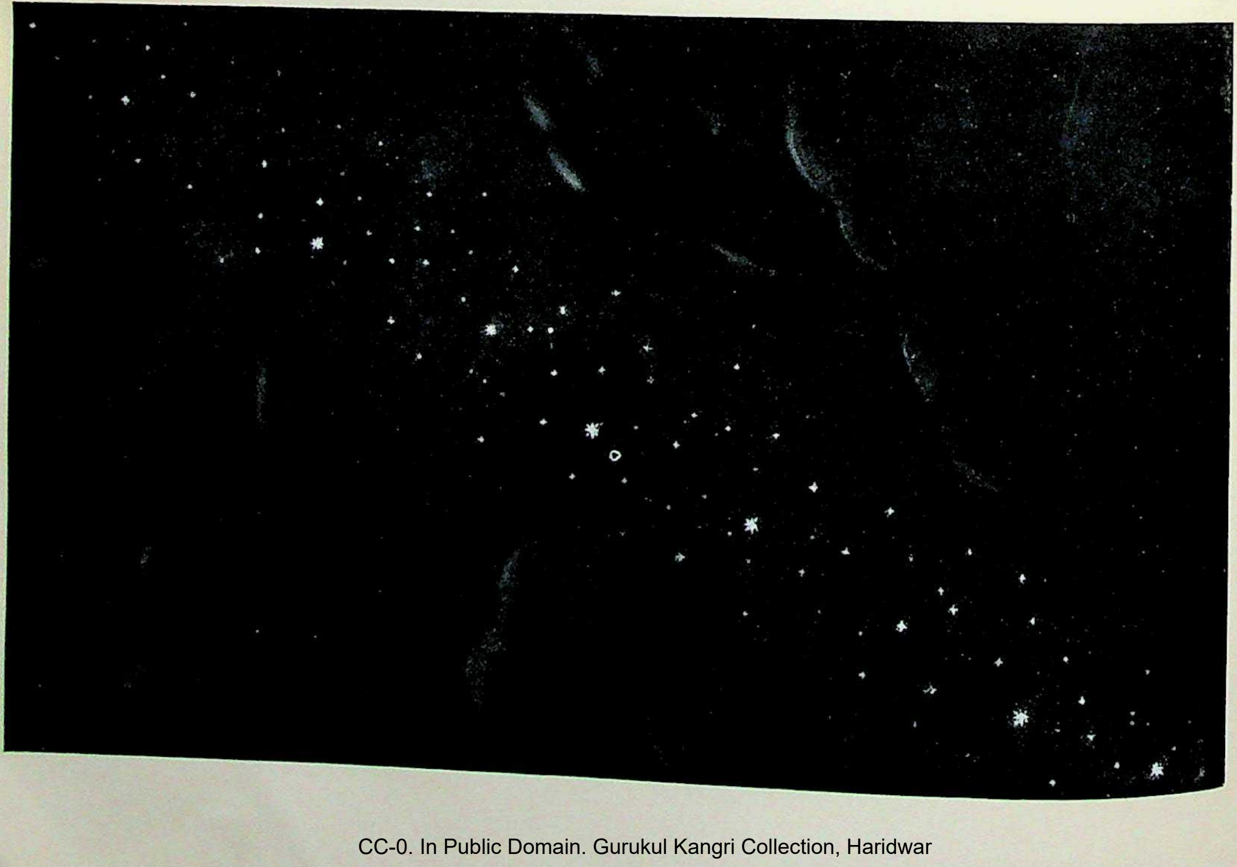


FIGURE 5–*The Milky Way as seen 'through a very good reflector.'*

(Figures [illegible] are from the Original Theory.)

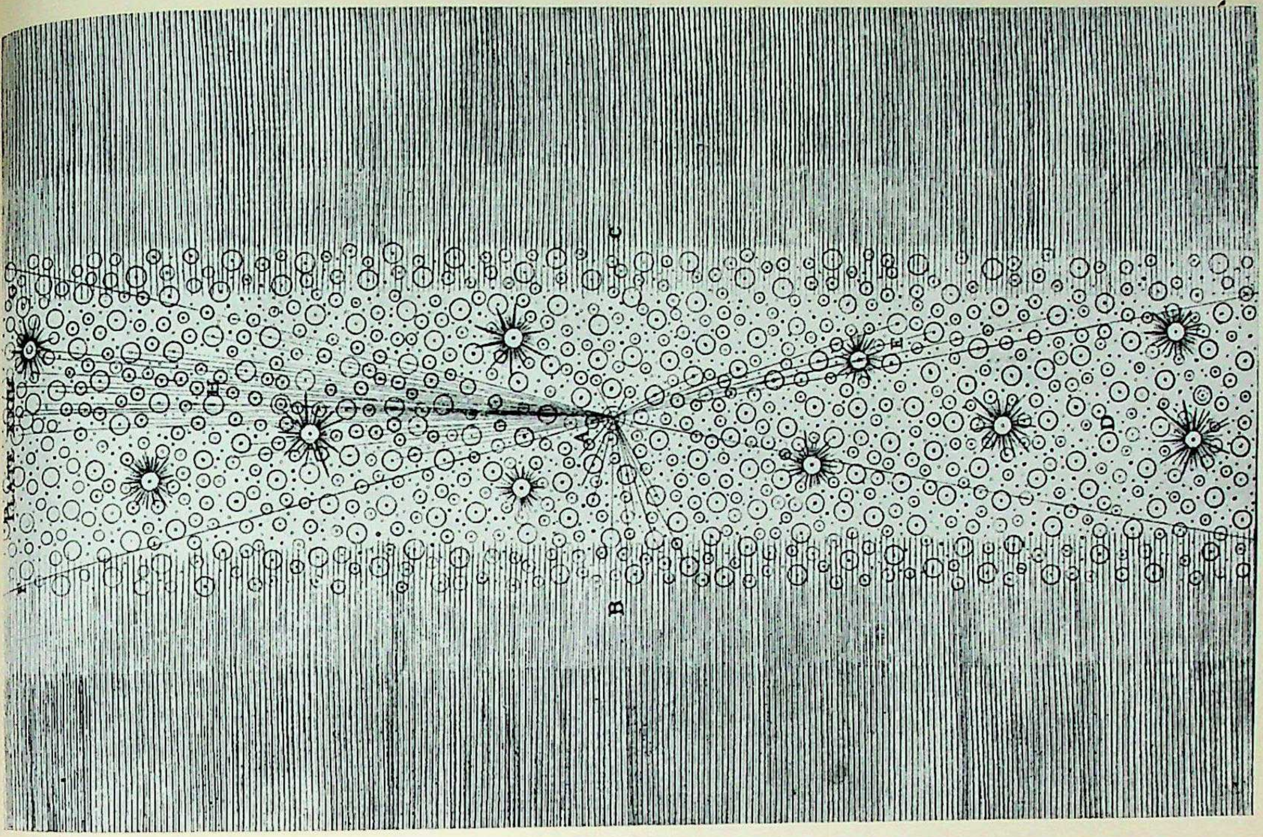
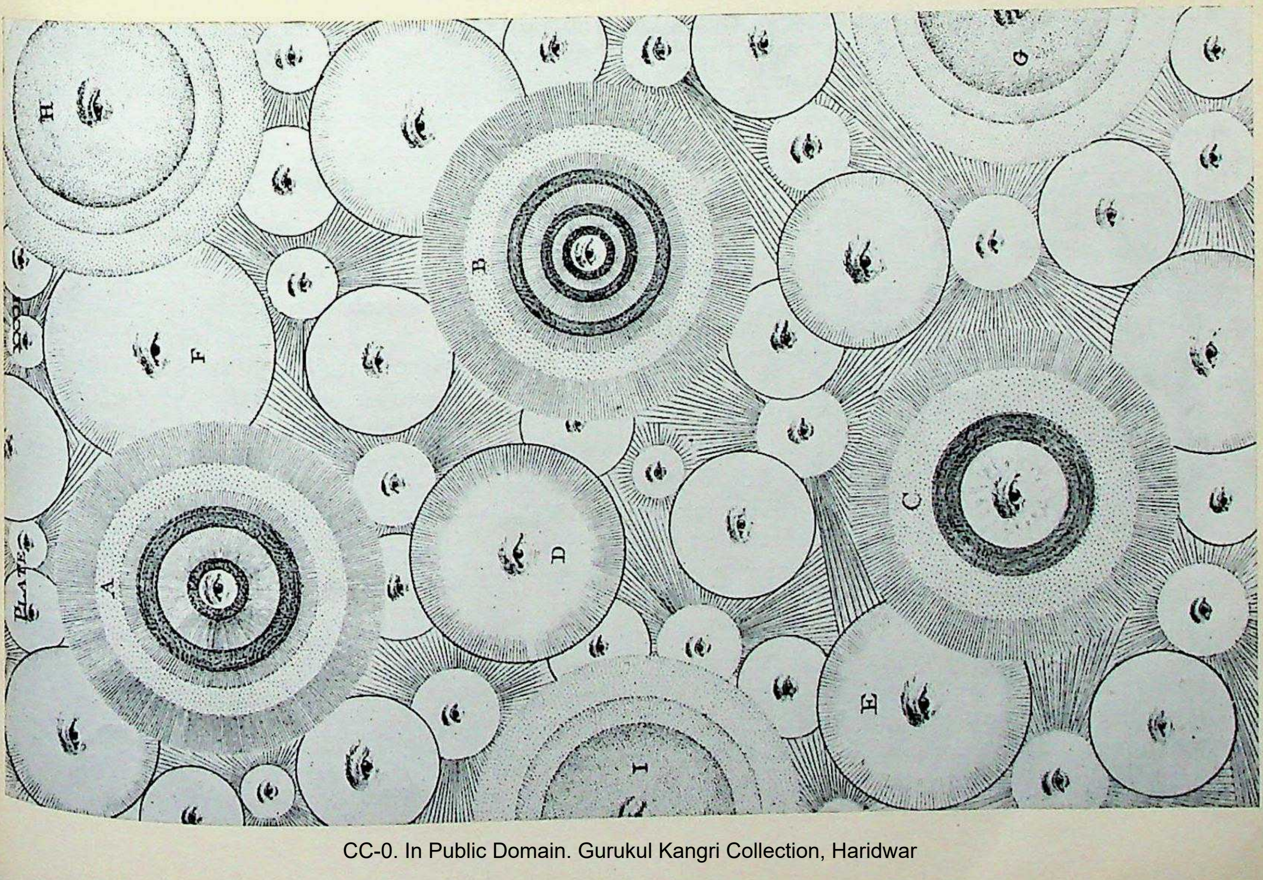


FIGURE 8 – *Diagram of the Milky Way.*



PLATE
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FIGURE 7 – *'A finite View of Infinity.'*

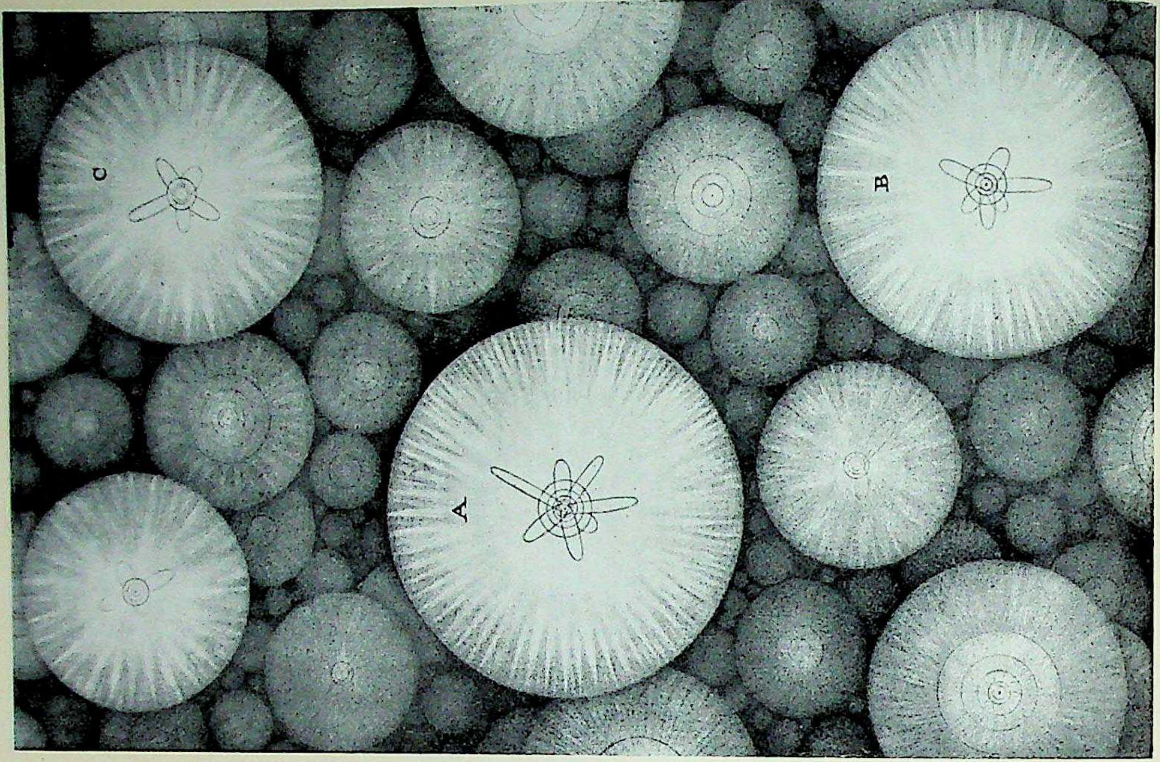


FIGURE 9 – '*Perspective View of the visible Creation.*'

of Planets and Comets; and that each hath a gravitating Power independent of each other,' so that 'these several Systems cannot interfere with one another.' From this passage it is clear that Wright meant by the enveloping spheres represented on his plates the boundaries of the independent forces of gravitation. This queer idea shows very strikingly what a gap there was between his natural philosophy and that of Kant, who assumed the validity of Newton's law throughout the whole universe, attraction being 'unlimited and universal,' reaching 'to all the distance of nature's infinitude.'

Among the many diagrams in Wright's book there are two which are meant not only to be illustrations in a qualitative way, but to help professional astronomers in their studies on the position of stars. Wright firmly believed that the 'fixed' stars were moving, and in order to enable future astronomers to establish this fact beyond doubt he made an attempt to transmit to them the relative positions of the main stars in the Pleiades and in Perseus exactly as they appeared to him. As his fine pictures of these constellations, mentioned above, were obviously not suitable for the delicate task, he supplemented them by geometrical drawings. From figure 10, which represents the Pleiades, can be seen the way in which he connected the stars by many straight lines; he considered their positions as the corners of triangles, and hoped that any movements of the stars could in future be detected by the disappearance of such regularities as shown in his plates. It is rather strange, but very characteristic, that he relied entirely on engraved plates for such difficult comparisons, and did not trouble to give numbers for the positions of the stars he had observed. Moreover, if the Pleiades should move as a group—as they actually do—their relative positions would not show any variation from his drawings.

Wright was obviously always happy if he could exchange the pen for the engraving tool; the figures he drew were of no real value for the purpose of observing star movements, but we may perhaps see in them an inkling of the decisive help which today the infinitely more exact photographs of the stars give to astronomy. When modern observatories store thousands of photographic plates for future comparisons they do in principle exactly what Thomas Wright intended with his laboriously prepared copper plates.

To do justice to him and to his peculiarities as an author we must not forget the kind of readers he had to reckon with. The subscribers to his book were the same gentlefolk whom he taught orally as an instructor, and this may explain not only the unnecessarily large number of illustrations but also his habit, so distracting to modern readers, of constantly interrupting his scientific discussions by theological digressions, exhortations, and quotations from poets. The scientific contents of the *Original Theory* could easily have been presented in less than half of its eighty-four pages, and Wright's interesting views on various astronomical questions would then have stood a better chance of being noted by his scientific contemporaries. He was probably completely 'original' only in his explanation of the Milky Way, but it is certainly noteworthy that in his book he inclines also to the modern interpretation of Saturn's ring as consisting of small particles. Some writers on astronomy give him credit for the conjecture that 'could we view Saturn thro' a Telescope capable of it, we should find his Rings no other than an infinite number of lesser Planets, inferior to those we call his Satellites.' Kant, however, who discusses the theoretical difficulties, following from Kepler's law, which beset the assumption of a solid ring, mentions that as early as 1705 Cassini had suggested that Saturn's ring might be a swarm of small satellites. It is quite likely that Wright too—who cared less than Kant for exact references—had seen Cassini's paper. On the other hand, it is possible that he had no forerunners in his interpretation of the nebulae as systems similar to the galaxy, and that this was one of the points in which he influenced Kant—although the Hamburg abstract which the latter saw does not make Wright's opinion clear. In any case, Kant's main argument for this interpretation of the nebulae, viz. their appearance as elliptical figures, is not to be found in Wright's book.

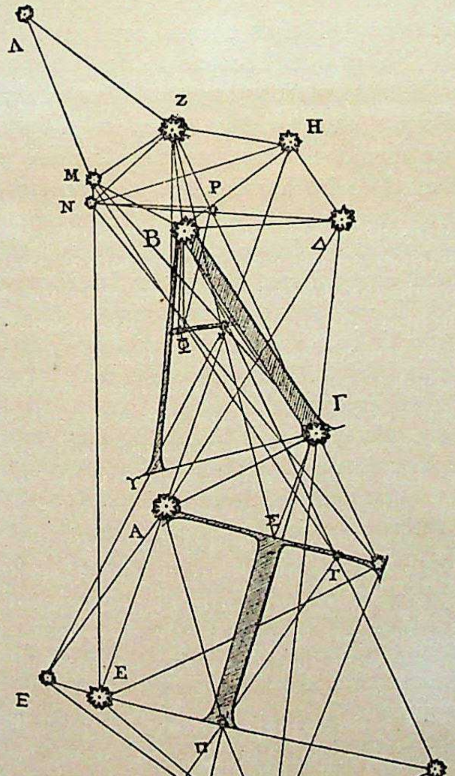


FIGURE 10 – *Diagram of the Pleiades.*

A merit of De Morgan's article, mentioned above, is that of having drawn attention to the only source of biographical information about Thomas Wright. Shortly after his death a personal friend, George Allan of Darlington, published anonymously in the *Gentleman's Magazine* 'A Sketch of the Character of Mr. Thomas Wright, late of Byer's Green Lodge, in the County of Durham' [1]. Unfortunately Allan was an antiquary without scientific judgment; he was mainly impressed by the social success of his hero. Thomas Wright, the son of a carpenter, born in 1711 in the little village of Byer's Green six miles from Durham, hampered in his education by a defect in speech, had in middle life become the fashionable tutor in astronomy and mathematics of the ladies of the English aristocracy, spending his days on the estates of dukes and earls, hunting and dining with them. To one of them he owed the annuity which enabled him to reside in later years as a gentleman of leisure in the large house which he built for himself in his native village, and the interior of which he decorated most elaborately with pictures, prints, and verses from his favourite poets. Here he lived, unmarried, in philosophic serenity, among books and instruments, and occupied with plans for the erection of a private observatory, until he died in 1786. He is buried in the churchyard of St Andrew's at Bishop Auckland.

He was soon forgotten. The author of the obituary note naturally did not succeed in awakening the interest of scientists by tracing the picture of a tutor in noble families who excelled in the popularization of astronomy. He gives hardly any information about Wright's serious studies, but mentions admiringly his erection, in the gardens of his rich patrons, of large models of the solar system, the construction of an 'astronomical fan for the ladies,' and the embellishment of his various books by copper plates. All he has to say in praise of the *Original Theory* is just: 'it is illuminated with a great many plates'; but he was at least interested in these plates and purchased the original coppers out of Wright's estate. He also bought his collection of pictures and prints, but a peculiar misfortune seems to have prevented the survival of any of these relics. Allan's collection passed into the possession of the Newcastle Literary and Philosophical Society, and it is not unlikely that they contained books and pictures, perhaps also instruments, from Thomas Wright's house; but a fire destroyed much of the Society's property in 1893, and nothing relating to Wright can be found there today. His house in Byer's Green is still standing, no longer as the elegant residence of a retired gentleman but as three small flats; it is closely surrounded by cheap houses which take the place of Thomas Wright's beloved gardens and orchards. In his days no house was less than a hundred yards from his own. The west terrace on which he liked to dine in the open air has also vanished, so that it is not quite easy to recognize in the drab 'Byer's Green Hall' of today (see figure 4) the eighteenth-century residence of which he himself once gave a glowing description in a letter to a friend [2]. Still less has survived of the 'composition of dials' Thomas Wright erected on the pier at the mouth of Sunderland harbour; it must have been a substantial piece, because he received a gratuity of 20 guineas for it, and a description was published at the expense of the town; but the pier was reconstructed in 1786, and nothing is known about the fate of Thomas Wright's sundials.

One structure, however, seems to have been preserved exactly in the state in which Thomas Wright left it: the 'gothic tower on one of the highest hills in the country,' as he calls it (see figure 2). It belongs to the little village of Westerton, two miles distant from Wright's residence in Byer's Green. It was meant to become his private observatory, but was never used as such because he died before he had equipped it. Most likely it was never used for anything, if we disregard its service as an observation post during the last war. This seems to be implied by the name 'Westerton Folly' under which it is known locally, by the great difficulty encountered in an endeavour to discover its present owner and to get access to it, and by its complete emptiness. The spiral wooden staircase within lacks a few steps and is far from safe, but whoever climbs to the top of the tower will be surprised by the magnificent view it commands of the surrounding countryside, with Durham cathedral in the distance. Its place was certainly well chosen.

The University of Durham celebrated the 200th anniversary of the publication of Thomas Wright's *Original Theory* by an exhibition of his books—one of them existing only as a single copy recently purchased for Durham—and the unveiling of a memorial tablet at his observatory tower. It also invited speakers from other universities to give addresses on Thomas Wright and the general scientific background of his time. Nobody will try to follow Rafinesque and put Thomas Wright on the same level as Newton, but it is felt that too few people still know exactly what Wright's merits are, and that his *Original Theory* has become a not unimportant link in the history of astronomy. What Rafinesque valued most, the florid passages in Wright's last letter on theological and moral principles (which he believed to be localized in the centre of the universe), are just those which Kant treats with hardly concealed irony and dismisses briefly as 'fanatical enthusiasm.' Neither Rafinesque nor Wright's friend Allan could 'restore him to life and fame,' because what they admired, and what no doubt Wright himself considered important, was either irrelevant or could not stand serious criticism. On the other hand, his one great idea, the explanation of the Milky Way, does not seem to have occupied his thoughts in later years; he never returned to it, and the 'useful applications' quite obviously escaped him. It was only Kant who saw them, and who could therefore tell what was of permanent value in Wright's book.

It is impossible to overrate the influence which British science and philosophy exerted on Kant's development. Throughout his life he faithfully followed Newton's doctrines, and when writing his *Universal Theory of Celestial Evolution* he prefaced it by an 'Outline of the most necessary principles of Newton's Natural Philosophy' required for the understanding of his own work. His original philosophical period started with the reading of Hume, who, in his own words, 'awakened him from his dogmatic slumber.' In

Wright we meet another Englishman who decisively helped Kant to formulate his own ideas, a fact which is all the more noteworthy if we remember that Wright left no mark at all on the development of astronomy in his native land.

It is an old and very obvious truth: *pro captu lectoris habent sua fata libelli.* The fate of a book is determined by the capacity of the reader; it cannot, however, have happened many times that one reader alone—and in a foreign country at that—saw a spark of genius amid much indifferent writing, and by adopting and developing the one brilliant idea saved the memory of the author from oblivion.

LITERATURE ON THOMAS WRIGHT

[1] 'A Sketch of the Character of Mr. Thomas Wright, late of Byer's Green Lodge, in the County of Durham,' *Gentleman's Magazine*, **63**, 6 and 126, 1793. The author of this anonymous article had been a friend of Wright and could base his statements on personal observations and Wright's own notebooks. This is the only original source of information on Wright's life; paragraphs concerning him in biographical dictionaries and topographical works (on Darlington, Bishop Auckland, the county of Durham, etc.) are mostly copied *verbatim* from it. Wright's portrait prefixed to the article is similar to the engraving reproduced here (see figure 3), but much cruder.

[2] 'Mr. Wright's Description of his Villa at Byer's Green,' *Gentleman's Magazine*, **63**, 213, 1793. A very characteristic letter by Wright to a friend, published as an appendix to the above article.

An appreciation of Wright's scientific achievements and of his influence on Kant is to be found in the following papers:

[3] De Morgan. 'An Account of the Speculations of Thomas Wright of Durham,' *Philosophical Magazine* (3), **32**, 241, 1848.

[4] Sampson, R. A. 'Thomas Wright, the Durham Astronomer,' *Proceedings of the Society of Antiquaries of Newcastle-upon-Tyne*, **8**, Jan. 1895 to Dec. 1896.

[5] Hastie, W. 'Kant's Cosmogony,' James Maclehose and Sons, Glasgow, 1900.

[6] Paneth, F. A. 'Thomas Wright of Durham and Immanuel Kant,' *Durham University Journal*, N.S., **2**, 111, 1941; reprinted, somewhat abbreviated, in *The Observatory*, **64**, 71, 1941.

Copious abstracts from Wright's biography and books are contained in:

[7] Gushee, Vera. 'Thomas Wright of Durham, Astronomer,' *Isis*, **33**, 197, 1941. The genuineness of the portrait added seems very doubtful.

BOOKS PUBLISHED BY THOMAS WRIGHT

Pannauticon, 1734. According to Wright's biographer, a treatise on navigation sponsored by the Navy and published by subscription. Strangely enough, no copy and not even a record of this book could be traced in any library.

The Universal Vicissitude of Seasons, 1737, seems to exist only in the one copy which, since 1948, is in possession of the Durham University Library. Diagrams and ornaments are drawn and coloured by hand, so that this curious work, in spite of the use of copper plates, is nearer to a manuscript than to a print.

The Use of the Globes, 1740. A booklet written at the request of John Senex, F.R.S., to serve as an instruction for the use of his terrestrial and celestial globes. Now rare.

Clavis Coelestis, being the Explication of a Diagram entituled a Synopsis of the Universe: or, the Visible World Epitomised, 1742. A popular introduction to astronomy, with three large plates, each containing several figures. These plates are of such an awkward size that in some copies of the book they have been cut into quarto sheets; in others they are badly damaged or even missing.

Louthiana, 1748. A description of the antiquities in the Irish county of Louth. The illustrations, some of them signed by Wright, show both his technical skill and his limitations as an artist. Copies in many libraries.

An Original Theory, or New Hypothesis of the Universe, 1750. Wright's chief publication, the subject of the present article. Four copies in Durham libraries; a few others elsewhere.

The Longitude Discover'd without use of Graduated Instruments, 1773. According to Miss Gushee a copy of this work is preserved in the New York Public Library.

In the custody of the British Museum are two of Wright's manuscripts: the 'Journal,' on which the biography in the *Gentleman's Magazine* is largely based, and 'Observations on . . . Remains of Antiquity . . . taken on a tour through England' (British Museum Add. MSS. 15627 and 15628).

The Royal Society possesses a few letters by Thomas Wright on astronomical and archaeological subjects, and the Royal Astronomical Society a calligraphic letter, 'To their Excellencis the Lords Justices of the Kingdom of Ireland,' in which Wright proposes to draw an accurate map of the ports, rocks, etc., of the shore of Ireland in the interest of navigation.

Colour in the day sky

JAMES PATON

'. . . there is not a moment of any day of our lives when nature is not producing scene after scene, picture after picture, glory after glory, and working still upon such exquisite and constant principles of the most perfect beauty. . . .' (Ruskin, *Modern Painters*). This article explains some of the optical phenomena which lend colour and splendour to the day sky.

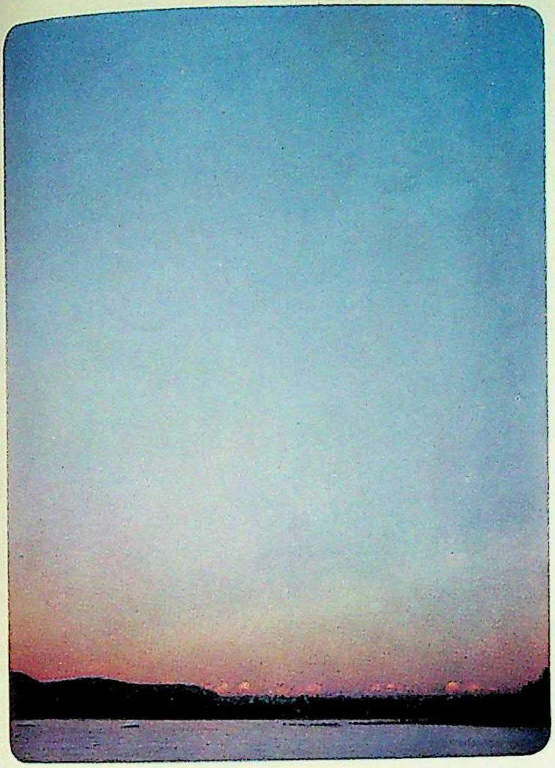
While the colour of the cloudless day sky is predominantly blue, any colour or combination of colours of the visible spectrum may appear if prevailing conditions are suitable. Especially near dawn and sunset, portions of the sky may display tints ranging from vivid purple and dark red, through orange and yellow, to green and violet (though the eye is not strongly sensitive to violet). When scattered rain clouds are present, there may appear a concentration of spectral colours in the rainbow; when the tenuous sheet of ice crystals composing the cirro-stratus cloud extends in front of the sun, the coloured rings and arcs of the halo may be visible; when the clouds consist of particles of the requisite size and concentration, those near the sun may show the iridescent sheen characteristic of a corona. If, however, the canopy of cloud becomes thick and unbroken, the intensity of the light is so reduced that both sky and landscape assume a uniform greyness.

It was not until the latter part of the nineteenth century that a satisfactory explanation of the cause of the blue of the sky was forthcoming. Brücke, and later Tyndall, showed experimentally that a suspension of small particles (through which objects can be seen clearly) appears blue when illuminated by white light, and Lord Rayleigh demonstrated theoretically that light scattered by atmospheric molecules 'would suffice to give us a blue sky not so very greatly darker than that actually enjoyed.' In fact, he showed that the intensity of light scattered by a single particle of dimensions small compared with the wavelength λ of light varies inversely as λ^4, so that sky light, being scattered sunlight, contains all the spectral colours, but those of the shorter wavelengths, violet and blue, appear in by far the greatest intensity (top curve, figure 1, p. 131). The sun is most markedly red at dawn and sunset, because then its light is most effectively depleted of the shorter wavelengths by its passage through the maximum thickness of air.

When a shadow due to an extensive cloud sheet is cast on the path of light coming from clear sky near the horizon (figure 2), the distribution of light intensity among the different colours may be so altered by further scattering as to cause the distant sky to appear orange or, less frequently, green. The curves of figure 1 show that as the distance OA increases, the proportionally greater scattering of the shorter wavelengths causes the maximum to move from blue to green and eventually to orange, the last requiring a path of about 30 miles. This unusual coloration may develop whenever, as for example at twilight, light from a portion of the sky traverses a region in shadow. The light that first returns to the sky at the horizon after a total eclipse of the sun is orange in colour.

While small particles scatter preferentially the violet and blue with an intensity which is almost independent of direction, larger grains, e.g. larger dust particles and water drops, scatter all colours equally but almost entirely in directions close to that of the incident light (figure 3). The latter fact explains the increase in brightness and whiteness of the sky towards the sun. It is at an angle of about 90° from the sun that the sky is darkest and most blue, for only the smallest particles—mainly molecules—are effective in directing light in this direction: hence the deep blue of a clear zenithal sky at dawn and at sunset (plate 12). The sky becomes again whiter and brighter towards the horizon (plates 7 and 8), partly because there is a greater concentration of larger particles close to the earth's surface, and partly because of the greater optical thickness of the air in this direction. For, although each distant molecule scatters the blue and violet preferentially, these are just the colours which are most strongly depleted during the passage to the observer, so the composition steadily approaches that of white light (figure 1). This whiteness along the horizon changes to orange at sunset.

While the presence of fine dust adds to the blue



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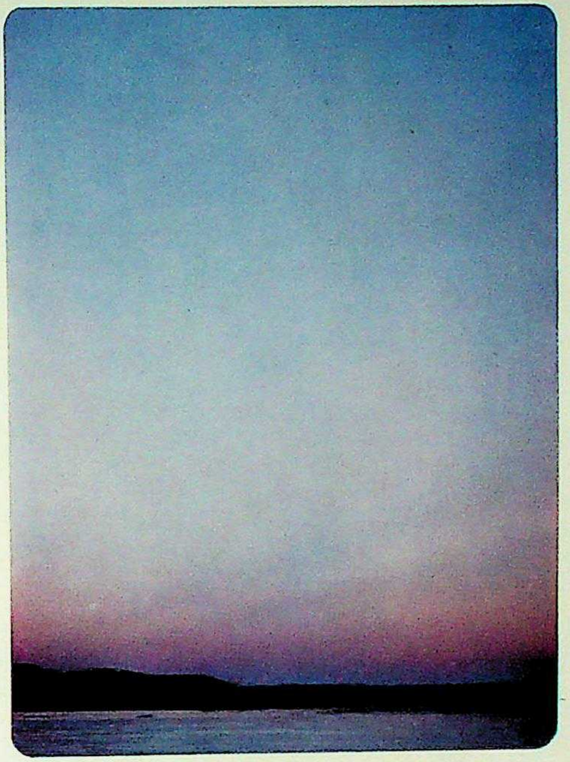

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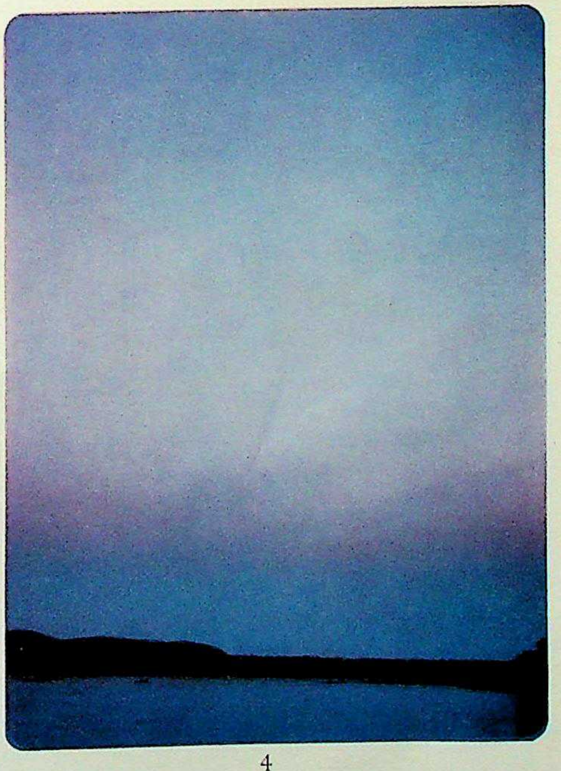

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PLATES 1–4 – *The eastern sky around sunset:* (1) *At sunset;* (2) *seven minutes after sunset;* (3) 15 *minutes after sunset;* (4) 21 *minutes after sunset. Observe the ascending earth shadow, the twilight arch, and the anticrepuscular rays (formed by clouds on the western horizon) in the counter twilight. Clouds on the eastern horizon (plate* 1) *remain bright after the foreground has become dark.*

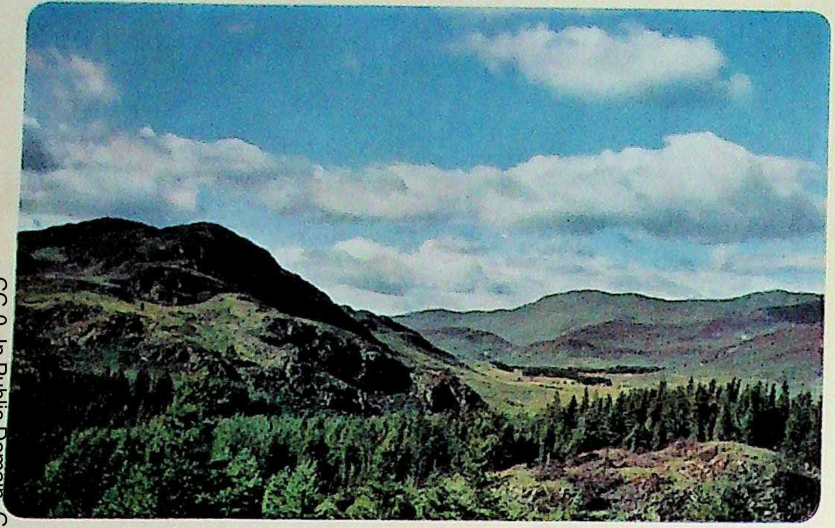


PLATE 5 – *The effect of large particles in suspension in the atmosphere. Glen Lednock, Perthshire, in clear conditions.*

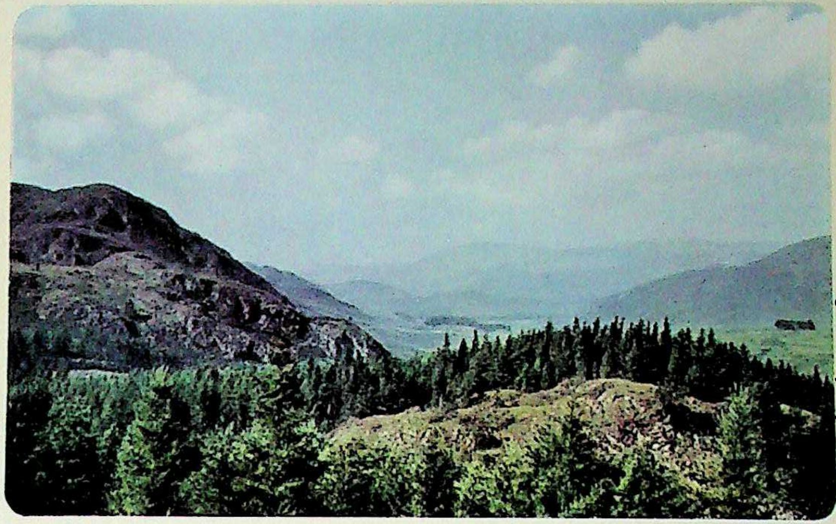


PLATE 6 – *The same view in mist.*

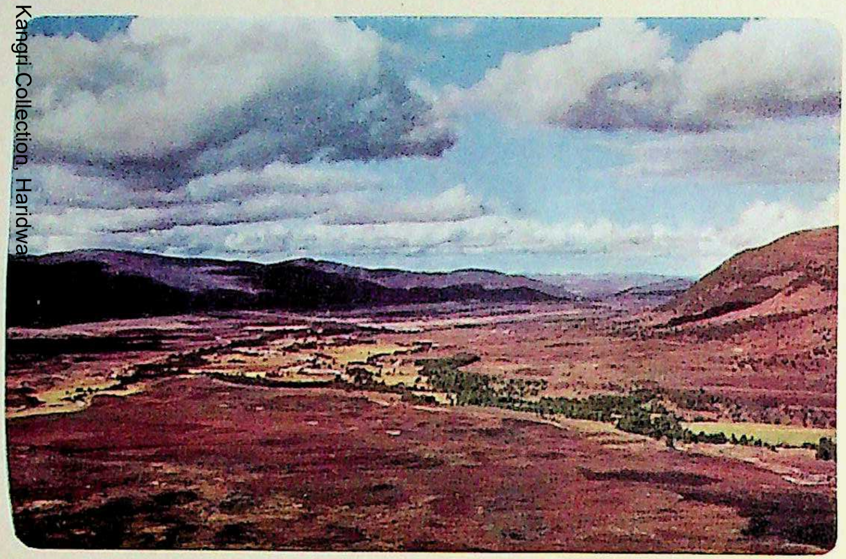


PLATE 7 – *Light and shade in cumulus clouds. Glen Feshie, Inverness-shire.*

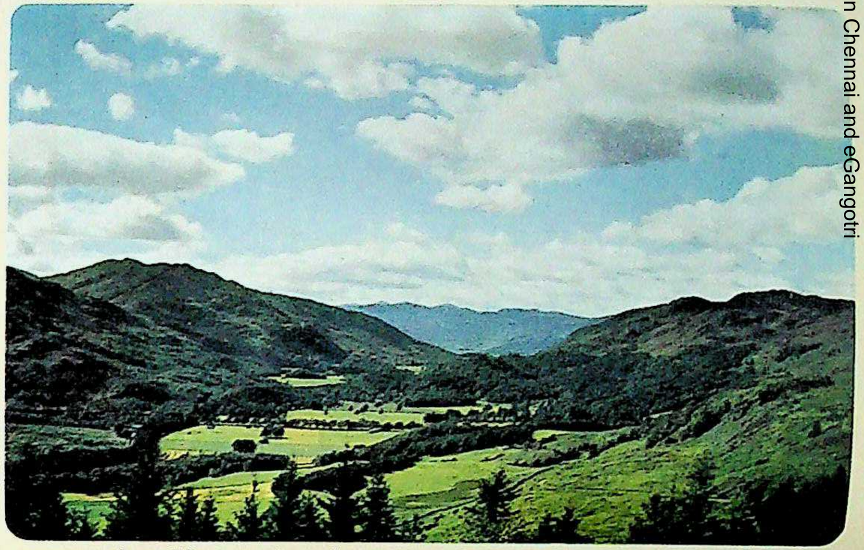


PLATE 8 – *The extension of the blue of the sky in front of distant hills. Strathearn, Perthshire.*

PLATE 7 – *Light and shade in cumulus clouds. Glen Feshie, Inverness-shire.*

PLATE 8 – *The extension of the blue of the sky in front of distant hills. Strathearn, Perthshire.*

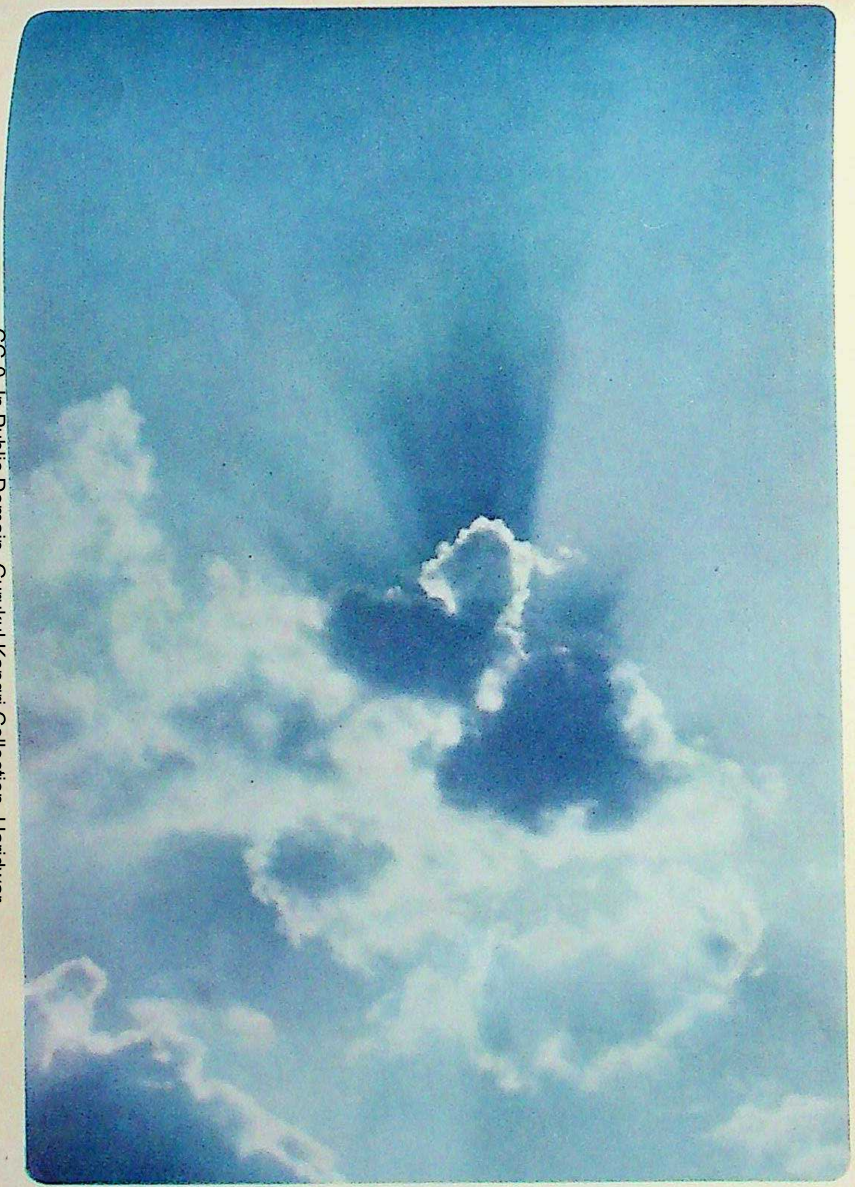


PLATE 9 – *'The sun drawing water.' Crepuscular rays.*

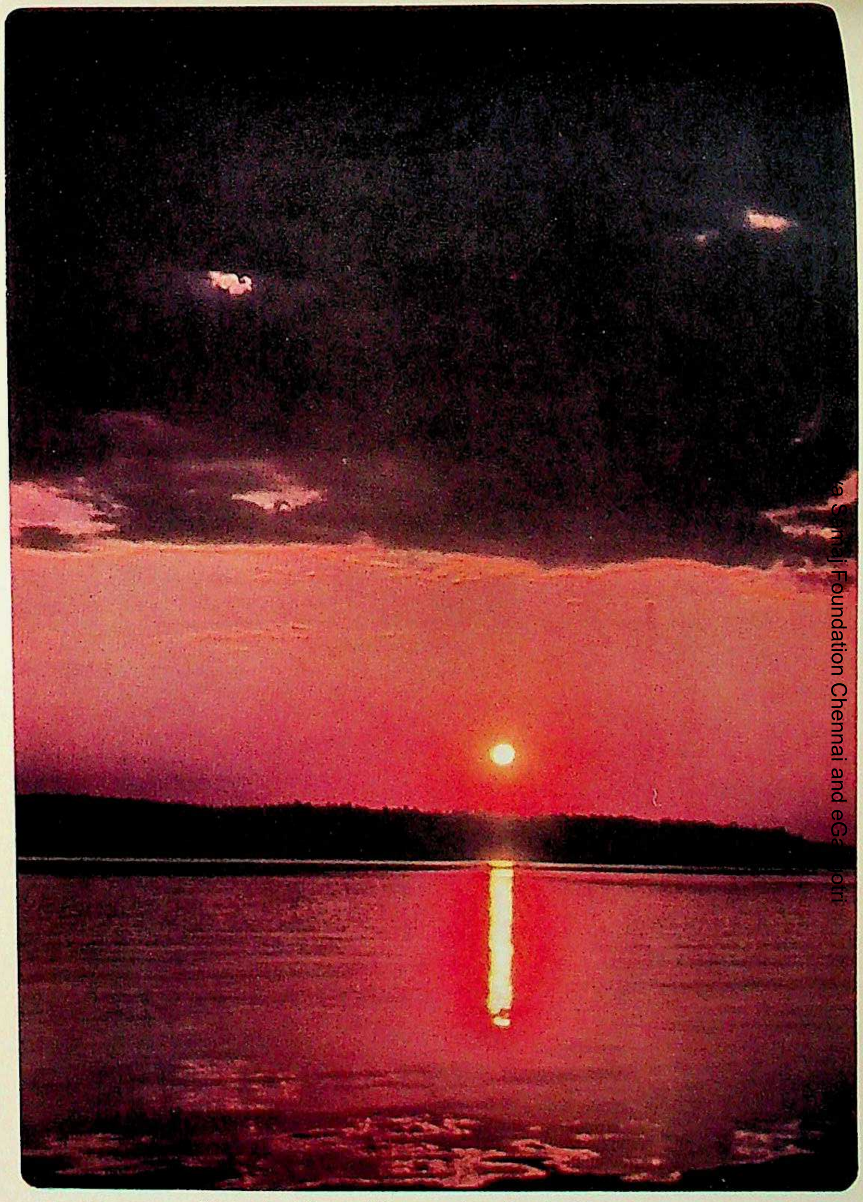
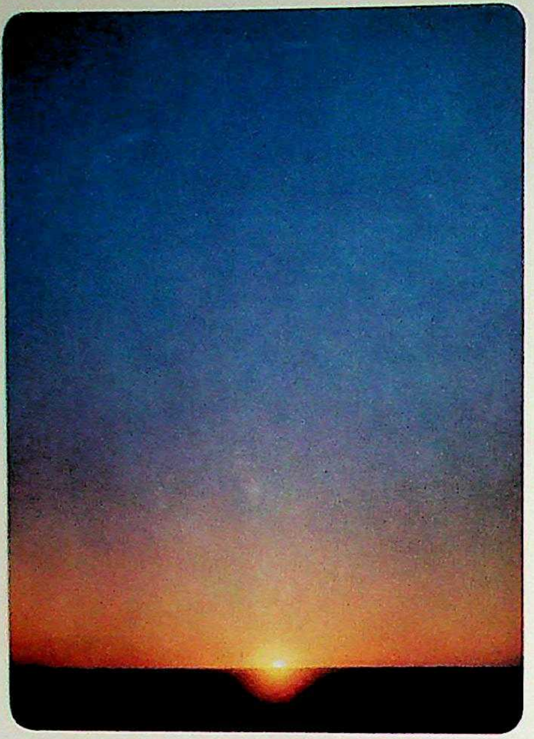


PLATE 10 – *Bishop's Ring. Photograph taken in Canada some days after a volcanic eruption in Iceland.*



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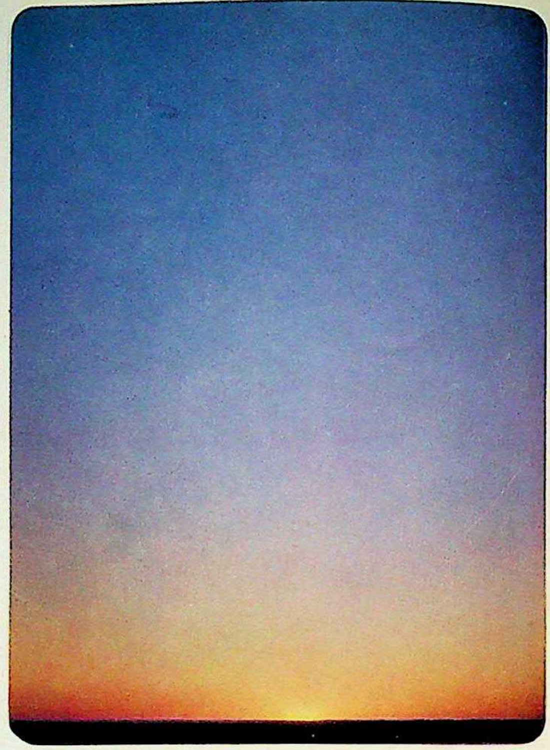

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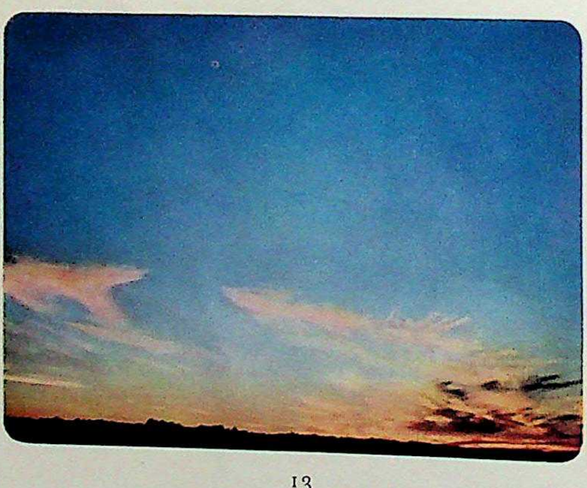

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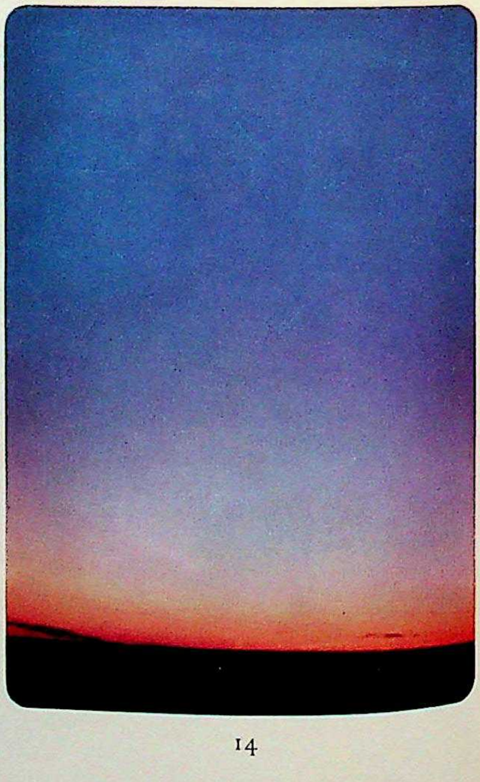
PLATES 11–14 – *The western sky at sunset. The afterglow:* (11) *One minute before sunset;* (12) *sunset;* (13) 18 *minutes after sunset;* (14) 30 *minutes after sunset.*



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of the sky and enhances the red of the sunset, as in industrial areas and after volcanic eruptions (plate 10), larger particles whiten (or, in the case of smoke particles, add their own colour to) the blue, their effect being readily observed in the marked deepening of the blueness after a heavy shower has carried them down to earth. When present in quantity in the lower atmosphere, dust grains or water droplets make visible the straight paths of rays that form the boundary of cloud or mountain shadows (plate 9). Although, of course, the rays are parallel, they appear by perspective to converge, like the ribs of a fan, to the sun or the anti-solar point (plates 1, 2, 3 and 4), and give the impression of 'the sun drawing water.' Being most frequently associated with twilight, they have become known as crepuscular rays, but they may be seen in suitable conditions at any time of day.

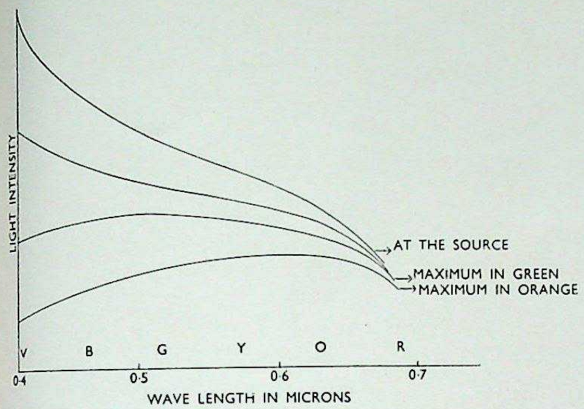


FIGURE 1 – *The change in the composition of light scattered by a small volume of air during transmission through increasing lengths of air path. The top curve shows the composition near the scattering element. The lower curves show the effect of further scattering with increasing distance from the source. The lowest curve would represent roughly the effect of passage through a path of about 30 miles in length.*

The suspension of water droplets that constitutes mist causes objects seen through it to appear whiter (plates 5 and 6), the mist itself showing up most clearly in directions close to that of the sun (figure 3).

The water drops in a cumulus cloud are so densely packed that its surface is an almost perfect reflector; where lit by direct sunlight it is a dazzling white, while parts in shadow are dark grey. A developing cumulus thus appears rocklike in form, with striking contrasts in light and shade (plate 7).

In clear conditions, when large particles are absent, the blue of the sky may be seen to descend in front of distant hills (plate 8). Scattering by the atmosphere between the observer and the hills adds blue to the light coming from the dark background, and provides a means of estimating distances by comparing the intensities of the blueness of distant horizons. There is a complementary effect, which is not so readily observed. In conditions of excellent visibility, snow-capped hills and cumulus clouds become more yellow the greater their distance. Here, the strong light from the bright background reaches the observer depleted of violet and blue, but this net loss of blue is small compared with the total intensity. When the distant background is dark, a very large proportion of the light that reaches the observer is directed to him by atmospheric scattering.

The geometry of the rainbow was first given by Descartes, who showed that when a ray of sunlight enters a raindrop and is reflected at the back surface, the direction of the emergent light is confined between the direction of the ray that falls normally on the drop and that of the ray of minimum deviation. Actually, this once-reflected light is so

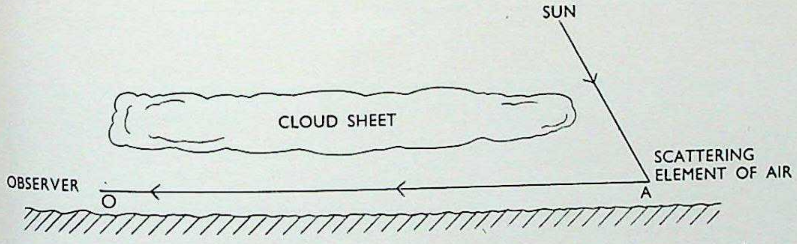
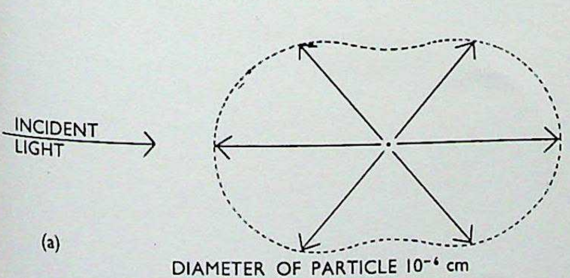
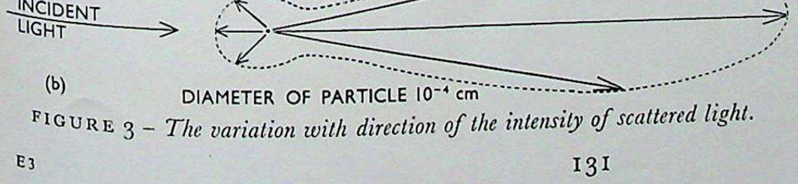


FIGURE 2 – *The passage of light from clear sky at the horizon to an observer across an unilluminated (shaded by a cloud) portion of the atmosphere.*



(a) DIAMETER OF PARTICLE 10^{-6} cm



(b) DIAMETER OF PARTICLE 10^{-4} cm

FIGURE 3 – *The variation with direction of the intensity of scattered light.*

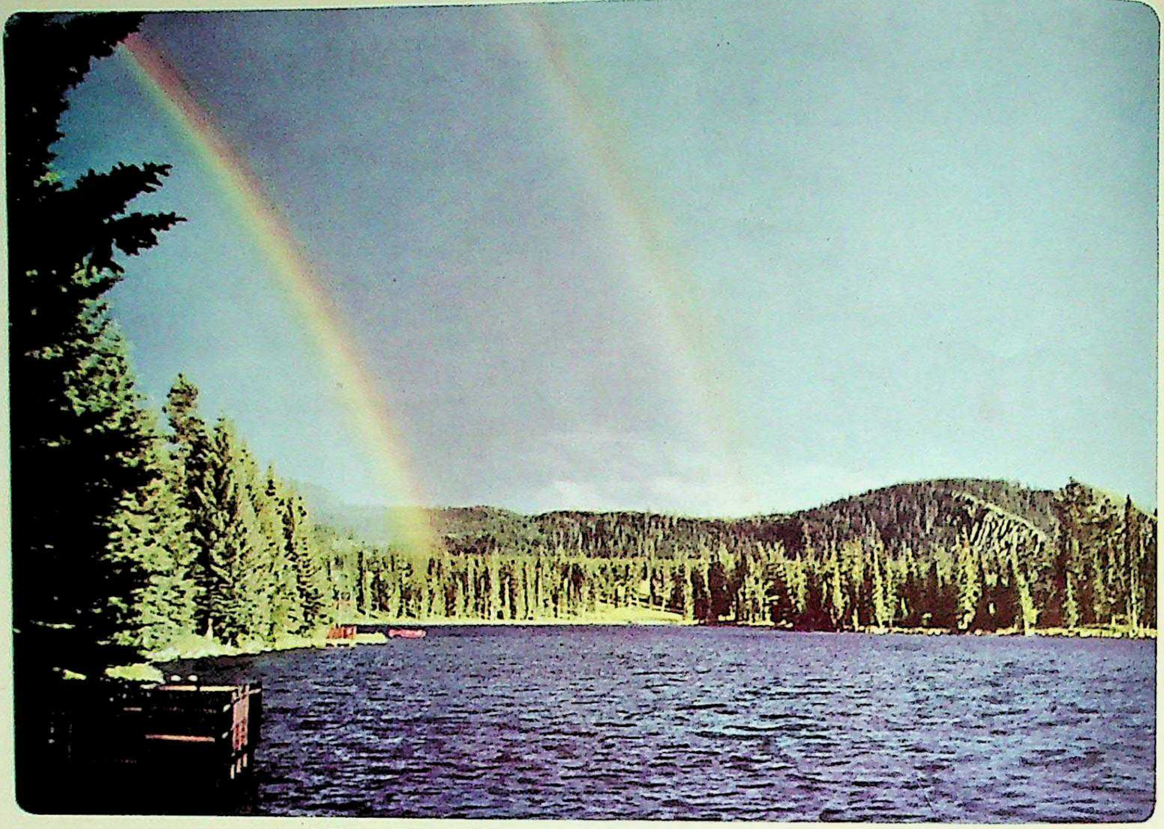


PLATE 15 – *Primary and secondary rainbows. Note the darker area between the bows.*

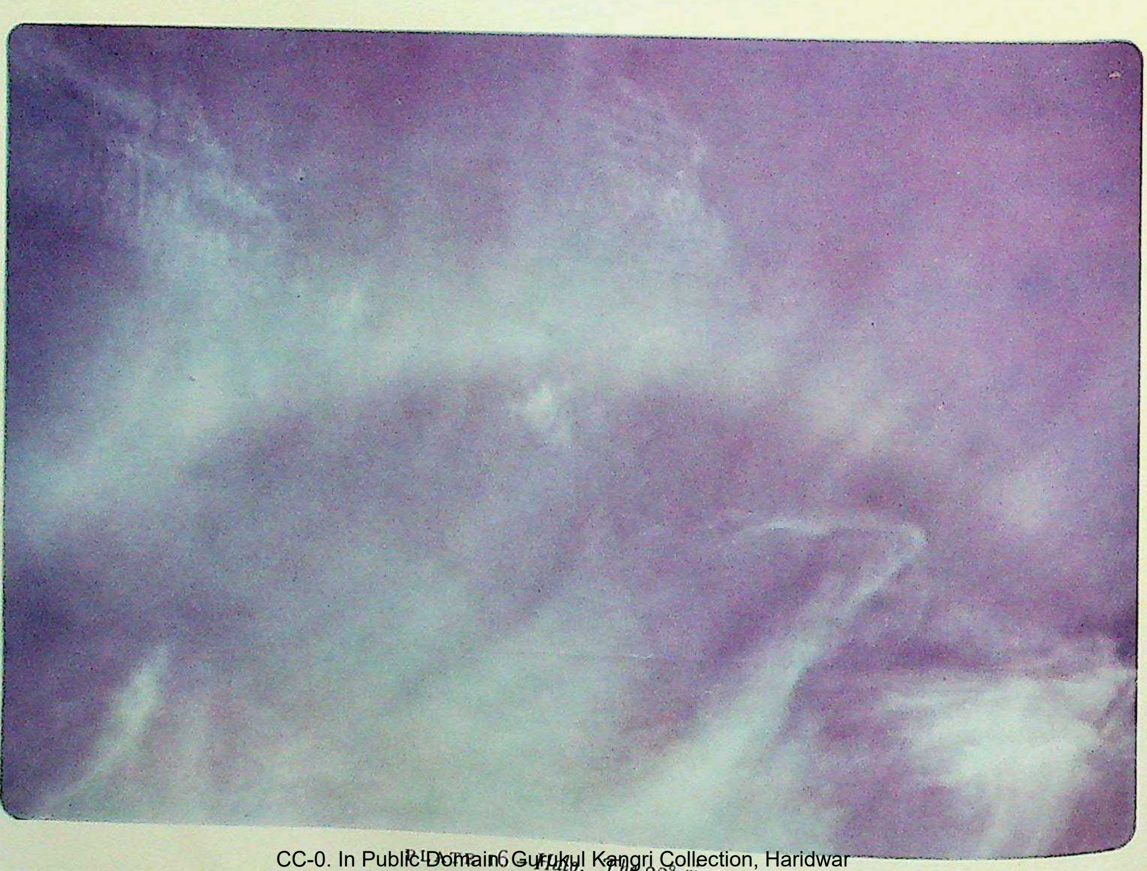


PLATE 16 – *Halo. The 22° ring.*

(Plates from Kodachrome transparencies by John F. Steljes.)

strongly concentrated in the latter direction that an observer in a position between an unobscured sun and a rain shower sees a bow (the primary bow), part of a circle of angular radius 42° whose centre lies on the line from his eye to the antisolar point. Because light that has been once reflected within a raindrop can reach the observer only from the part of the sky that lies below the bow, the region above the bow is generally darker than that below, but this contrast is often masked by sunlight reflected from the cloud background.

Light which suffers two reflections within the raindrop produces in the same way a bow of radius 51° (the secondary bow) with the spectral colours reversed. Twice-reflected light can reach the observer only from the sky above the bow, so that, if reflection by the cloud background is weak, the region between the red summit of the primary and red base of the secondary bow is markedly darker than the rest of the sky (plate 15). The supernumerary bows that appear outside the violet, below the primary and above the secondary bow, are interference bands, whose width and spacing are determined by the diameter of the raindrops. The rainbow colours become more vivid as the size of the raindrops increases.

The hexagonal ice crystals of cirrus and cirrostratus clouds provide a wide variety of possible paths for sunlight, and so may cause concentrations of the light in the rings, arcs, and parhelia that are classed as halo phenomena. Some, like the small 22° ring, are of common occurrence; others are rarely seen. Since a columnar hexagonal crystal refracts the light as a prism with refracting angle 60°, a minimum deviation of about 22° occurs at symmetrical passage, the refractive index of ice for yellow light being 1·31. As each crystal rotates towards and beyond the position giving minimum deviation, the direction of the emergent light changes only very slowly, so that there is always a larger number of crystals directing light around this direction than in others. Thus, in a haphazard arrangement of crystals, light is concentrated in the direction of the ray of minimum deviation, that is, in directions at 22° from the direction of the sun, to form a ring of 22° radius with a red inner border, for red suffers least deviation. Mainly because of the variations in deviation caused by tilting of the crystals, other colours almost disappear by mixing, and there is usually merely pale light beyond the red border (plate 16). As no refracted light reaches the observer from within the ring, the region just inside the ring is darker than the region outside it, but of course scattered sunlight, strong near the sun, may completely mask this effect.

Diffraction by the drops in a cloud veil covering the sun or moon is the cause of the formation of the reddish-brown-edged aureole, the corona, whose diameter and colour distribution depend on the size of the droplets. The iridescence that is sometimes seen on clouds at distances as great as 30° from the sun is almost certainly a portion of a corona produced by an assembly of minute cloud particles of uniform size. Occasionally, after the occurrence of a volcanic eruption, the sun may be continuously surrounded by a reddish-brown aureole—the 'Bishop's Ring,' so called because it was first observed after the Krakatoa (1883) eruption by the Bishop of Honolulu (plate 10).

Sunrise and sunset provide the greatest splendour of sky colour. In favourable conditions at sunset the earth's shadow, the blue-grey twilight arch, rises in the east carrying above it the coloured horizontal bands of the counter-twilight (plates 1, 2, 3, and 4): purple, crimson, orange, yellow, green, blue in order upwards, to merge into the diffuse illumination caused by reflection of the stronger light in the west. About forty minutes after sunset, the boundary line of the earth's shadow has become indistinguishable, and the counter twilight has usually vanished. The explanation of the bands of the counter twilight lies in the fact that the light illuminating the eastern sky becomes progressively more red, by scattering, the lower its path through the atmosphere. In the west, the yellowish, sometimes rosy glow, that has encircled the sun (see figure 3) as it approaches the horizon, remains visible in its upper portion for almost half an hour after sunset (plates 11, 12, 13, and 14), slowly changing in colour through pink to bluish white. While this gradually vanishes at about half an hour after sunset, there may appear for a short time the brilliant purple glow that becomes so striking when it illuminates the western sides of tall buildings. This may be due to the presence at heights of 10–20 km of a layer of fine dust, whose lower portions are bathed in red light while the upper parts receive light which, having traversed a region of more rarefied air, still contains much blue.

A comprehensive and excellent account of atmospheric optical phenomena will be found in Minnaert's *Light and Colour in the Open Air*. G. Bell and Sons Limited, London. 1940.

Parasites and war

GEOFFREY LAPAGE

The most cursory study of military history reveals that by far the greatest danger is not the armament of the enemy, but parasites which profit by the disorder of war to break the bounds which barely restrain them in normal times. In almost all military campaigns, from the earliest times up to the present day, such diseases as malaria, typhus, dysentery, and trichiniasis have exacted a heavy toll from both the troops and the populations of the battle areas.

Parasites of all kinds have throughout history exerted a powerful influence upon war. In the tropics especially, and in all the warmer countries, military commanders must reckon with their power to curtail or defeat the soldier's plans. Most people, no doubt, will be well aware of this fact. They will have read about, or heard of, the ravages of such diseases as typhoid fever and bacillary dysentery, which are caused by bacteria. Less well known is the fact that some animal parasites can exert as great an influence upon war as that exerted by bacteria and viruses.

Among the parasitic animals which attack man, perhaps the malarial parasites are the most powerful. Well known even in Hippocratic times, and probably much earlier, malaria caused, and still causes, so much illness that it is regarded by some experts as the worst of all human diseases.

The chronic ill-health that malaria causes, the large numbers of people killed by it, and its ability gradually to destroy the virility of whole nations, are well established in a vast literature. It has been suggested, for instance, that one of the factors which caused the degeneration of the Greek nation and their surrender to the Romans was the malaria that became prevalent in their country, and that periodic cycles of malaria in the Campagna coincided with fluctuations in the power of Rome and with its decline and fall. Widely distributed as malaria now is over the tropical and subtropical areas of the world, and in many temperate zones also, it is only nowadays that it is yielding to measures of control devised by modern science. These measures not only attack the parasites in the human body, but make it possible to eradicate malaria-carrying mosquitos from large areas of difficult country. The great pioneer feat which eradicated the mosquito *Anopheles gambiae* from Brazil has since been repeated in Egypt, and malaria-carrying mosquitos have been successfully attacked in Cyprus and elsewhere. There seems to be no doubt that we are well on the way to the control of this devastating disease, especially since the discovery of Paludrine (see ENDEAVOUR, 5, 65, 1946).

Although the world may be freed in the future from the menace of malaria, there is no doubt that until very recent times it has been a scourge providing a primary problem for military commanders operating in areas in which it is endemic. It has upset strategies and caused defeats, and, when it has attacked both sides in battle, all fighting has been stopped. Numerous instances could be cited to support this statement, but a few, taken from recent wars, must suffice. During the first world war, when the allies were operating in Macedonia, both they and the Germans suffered heavy losses caused by malaria, as readers who served in that area will remember. In 1916, about a quarter of the British Macedonian force of some 123,000 men had to be taken into hospital to be treated for malaria, and the French troops suffered equally severely. In 1917 and 1918, almost half the British force was put out of action by the disease. The German armies also suffered to much the same degree, and military operations were made impossible. In 1916, the East African expeditionary force of about 58,000 men was practically immobilized by malaria, some 50,000 of them being in hospital during that year. In 1917, 72,000 men were taken into hospital with malaria and 499 men died of it. In Iraq also, malaria reduced the effective forces considerably.

During the second world war, malaria remained a serious peril to the allied armies. Dr Hamilton Fairley, writing in *The Fight against Disease*, the organ of the Research Defence Society (1947), tells us that casualties caused by malaria in the south-west Pacific area during four months in late 1942 and early 1943 amounted to about 90 per cent. of the forces employed. Incidentally, he quotes figures which show that, during the early campaign against the Japanese in 1942–3, casualties due to disease were 5–30 times as numerous as those incurred in battle. This incidence of disease was experienced alike by British and Indian troops in Burma, by United States troops at Bataan and Guadalcanal, and by Australian troops in New Guinea and New Britain. At Bataan, about 85 per cent. of the men of each United States regiment had malaria, and some experts believe that the reverse of these troops was due as much to malaria as to any other cause. In addition to malaria, troops in this area suffered from bacillary dysentery, dengue fever, scrub-typhus, and various skin diseases, but the importance of malaria is shown by the fact that, of the medical casualties suffered by the Australian forces in New Guinea between September 1943 and February 1944, 60·8 per cent. were due to malaria. Although the Japanese forces also suffered severely, the menace of malaria to the British and their allies was very grave, and the researches described by Dr Fairley were given high priority. The result of this work was that the threat of malaria was controlled.

The malarial parasites belong to the group of single-celled animals called Protozoa, among which is also the amoeba (*Entamoeba histolytica*), which causes amoebic dysentery. This disease, which must be distinguished from the bacillary dysentery caused by bacteria, has also been a potent enemy of armed forces. Human beings are infected by the minute cysts of this amoeba, which pass out in the solid excreta and may get directly into the water supplies or food, or may be carried there by flies and other means. Efficient sanitation will therefore do much to eliminate this disease. Lack of effective sanitary measures led to a prevalence of amoebic dysentery, and probably other parasitic diseases, among the Axis troops in Egypt during the recent war. Certainly some of these troops left behind them, after the battle of El-Alamein, a legacy of insanitation which makes one wonder whether one of the causes of their defeat was not the dysentery from which they suffered. This state of things was the more remarkable because the German *Afrika Korps* was instructed in the risks of parasitic diseases with characteristic thoroughness, as part of intensive training for war in hot countries. In south-east Asia, the incidence of amoebic dysentery among allied troops was about 12 per cent., but in the south-west Pacific it was lower.

One reason why malarial parasites can exert such devastating effects upon man is the fact that, once they have been injected into him by a mosquito, they can multiply inside his body, as bacteria do. They also multiply inside the body of the mosquito which injects them into man. One mosquito bite may thus put into human blood enough malarial parasites to cause—when they multiply—a heavy infection which can overcome the defences of the human body comparatively rapidly. The parasitic roundworms, on the other hand, some of which are serious dangers to military operations, cannot multiply in this way, so that they exert their effects more slowly. If, however, enough roundworms get into the human body, their effects can be serious. Among the species of roundworms which have affected troops in action, the pork trichina worm (*Trichinella spiralis*), the large roundworm of the small intestine (*Ascaris lumbricoides*), and the filarial roundworms are probably the most important.

Trichinella spiralis, which causes the disease called trichiniasis, is usually acquired by man when he eats raw pork containing the larvae of this worm, or pork that has not been cooked sufficiently to kill them. On active service it may not be possible to cook pork effectively, or the soldiers may prefer it uncooked. A small German commando unit, for instance, operating on the Polish frontier during the 1939–45 war, halted for the night and appropriated a pig from a nearby farm. The men ate the meat raw, partly because they were very hungry, and partly because they could not advertise their presence by lighting a fire for cooking. Unfortunately for them, the pig's muscles were infected with the trichina worm, which is not uncommon in this part of Europe. The result was that they were all put out of action by trichiniasis.

More serious from the point of view of the enemy was the provision, for a German battalion operating in Norway, of a meal of raw or insufficiently cooked pork. Most of the battalion got trichiniasis and became casualties. Many of them sent presents of the meat to their friends or relatives in Germany, who also became infected. The German authorities subsequently had to deal with many cases of the disease among civilians.

Less serious, but serious enough, were the effects of the human pinworm (*Enterobius vermicularis*), which is a well-known parasite of children in all parts of the world. This worm is transmitted from one person to another by means of its eggs, which are laid by the female worm around the vent. The female pinworm comes out through the vent during the night to do this, and her emergence may cause severe itching, restlessness, and loss of sleep. German munition workers, herded into deep air-raid shelters and already severely worried by allied bombing, became infected with *Enterobius*, and the discomfort and insomnia which it caused became so severe that the output of munitions was affected. Special researches were therefore initiated to find a means of combating *Enterobius* and its effects. The incidence of threadworm among the allied forces, especially among certain sections of them operating at home and congregated in confined spaces, was also considerable.

The Guinea worm, which is probably identical with the 'fiery serpent' mentioned in the Bible as a plague of the Israelites (Numbers, Chap. 21, v. 6), is a roundworm which crippled an appreciable number of West African troops so severely that they had to be invalided out of the service. In the Far East, filarial roundworms were responsible for the disablement of troops by giving them the two diseases known as onchocerciasis and filariasis. The worms which cause onchocerciasis are transmitted by mango flies. They become enclosed in hard nodules under the skin and elsewhere, but the nodules do not usually cause serious trouble. The worms which cause filariasis, however, which are transmitted to man by mosquitos, may, after a number of years, cause the dreaded enlargement and thickening of the lower limbs and other parts of the body called elephantiasis. The worms require treatment, therefore, not so much because they incapacitate the soldier immediately, as because they have slowly progressive results and create, in the infected persons, reservoirs from which mosquitos may transmit the disease to others. There is also the risk that infected persons, returning to their home countries, may bring the infection with them, and may therefore establish the disease in parts of the world in which it was not formerly present. This can, of course, happen only in areas in which the species of mosquitos capable of transmitting the disease are to be found.

A similar risk is created by the return home of people infected with malaria and other parasitic animals. Mosquitos capable of transmitting malaria exist in England, for instance, especially along the coast from East Anglia to the Isle of Wight, and, after the first world war, the return of troops infected with malaria caused outbreaks of the disease in England. Similar legacies of wartime malarial infection occurred in Holland and other parts of Europe. A repetition of such outbreaks after the second world war was prevented by the energetic measures that were taken.

The parasitic worms called flukes are, on the whole, less injurious to troops, but the blood-flukes (e.g. *Bilharzia*), whose young develop in water snails and infect man either through his mouth or by penetrating the skin, can cause the commanders of armies a good deal of anxiety. The men must be instructed not to drink or wash, or even shave, in water likely to contain these young flukes, unless it has first been boiled or treated with chemical substances that will kill the parasites. Special precautions have therefore to be taken, and the work of the army authorities is much increased.

All the parasitic animals so far considered are species which live inside the body of man, and are themselves the causes of the diseases mentioned. There remain for consideration two species of parasites which do not themselves cause disease, but can transmit diseases which may rapidly reduce armies to impotence. These are the human lice which transmit to man the cause of epidemic typhus or jail-fever, and the larvae of the mite which transmits the cause of scrub-typhus. Both epidemic typhus and scrub-typhus are caused, not by the lice or mites which respectively transmit them, but by organisms which stand somewhere between the bacteria and the viruses and belong to the genus *Rickettsia*. Both diseases belong to the typhus group of fevers caused by *Rickettsia*, and must be distinguished from the typhoid group of fevers, which are caused by bacteria.

Epidemic typhus has always been a scourge of mankind. Probably some of the pestilences recorded in ancient times were epidemic typhus, which attacks human populations especially when their health is weakened by famine, or by the mass migrations caused by political upheavals or by war. It used to be very prevalent in ill-kept and insanitary prisons and thus acquired the name of jail-fever. The history of war is full of references to it. It must be distinguished from endemic typhus fever, which is a similar but milder disease caused by a different species of *Rickettsia*. Endemic typhus is limited to certain parts of the world and does not become epidemic. Usually it is passed from rats to man by species of rat fleas and rat lice, but human lice and rat fleas can transmit it from man to man.

Epidemic typhus, on the other hand, is transmitted from man to man by human head and body lice (*Pediculus humanus*), and for this reason it may spread rapidly to large numbers of people. It attacked Spanish soldiers during their conquest of Granada, and spread all over central Europe in the seventeenth century at the time of the Thirty Years' War. It has been a feature of most European wars. One of the most severe modern epidemics of it occurred in Serbia in 1915. When the epidemic was at its worst, as many as 2500 people were admitted to military hospitals every day, and about three times as many cases were known among civilians. From 30 to 70 per cent. of the infected persons died, and there were more than 150,000 deaths in six months. Poland also was at this time a centre of the disease. In 1918, after the war, a severe epidemic broke out in Rumania, causing 800,000 deaths, and in Russia, where some five million people were infected.

When the Italians attacked Abyssinia they benefited greatly by the fact that they kept themselves free from lice while the Abyssinians did not. Typhus was therefore completely absent from the Italian army, whereas the Abyssinians had about 20,000 cases in 1935. During the 1939–45 war, epidemic typhus broke out in Naples when the Germans were driven out of that part of Italy. The health of the Italian population of the city had been undermined by malnutrition and the destruction by the Germans of the sanitary services and water supplies, so that they succumbed readily to the disease. The vigorous use of pyrethrum, and of D.D.T., the effects of which were at that time only newly discovered, killed the lice and checked the outbreak. It was thus demonstrated that D.D.T., whose insecticidal properties had remained unknown for many years, could with proper use remove from human communities one of their most devastating scourges.

Scrub-typhus, which is better called mite-typhus (because this name distinguishes it from the louse-borne epidemic typhus), is a disease of Japan, Burma, and neighbouring areas. It is caused by a species of *Rickettsia* transmitted to man by the larvae of certain mites related to the 'harvesters' which annoy people in some parts of England and elsewhere. The disease has been known for a thousand years or more, and has been given various names, among which are tsutsugamushi disease, Japanese river fever, scrub-typhus, and mite-typhus. Rats, field voles, and probably other animals are reservoirs of the *Rickettsias* from which mites transmit them to man. During the recent war this disease became such a serious menace to our troops in the Burma area that strenuous efforts were made to control it. In order to try to prepare a vaccine against it, cotton rats were flown from America to England, and a well-equipped laboratory was built in record time to accommodate the team of specialists who made the vaccine. This brilliant team, who risked their lives—two of them died—to do a piece of work which was one of the outstanding feats of the war, had hardly produced their vaccine when the Japanese capitulated. Meanwhile, Australian workers, using human volunteers found that butyl phthalate was an effective means of dealing with the mites which transmit the cause of the disease. Rubbed into socks, canvas anklets and gaiters, trousers, and shirts, it killed the mites, and its use reduced the incidence of mite-typhus in New Guinea from 36 to 1 per 1000 per annum.

It is not possible on this occasion to consider other aspects of the relationships between parasitic animals and war. An interesting volume could be written on the part played by parasites, not so much in the destruction or immobilization of armies, as in causing the political changes which have led to wars. The spread of parasites, or of animals which transmit them, by the rapid means of transport used in both peace and war—aeroplanes, land vehicles, and ships—is another very important aspect of the subject which cannot be dealt with here. Both are chapters in the interesting general history of the effects of parasites upon the development of human civilization. If parasites can hamper or stop wars, they can also severely hamper human industries, especially in tropical countries. Some of the species which attack domesticated animals and certain crops, such as potato, wheat, barley, sugar-beet, and others, can greatly reduce the production of essential world food supplies. Clearly it is true that, if parasites are able to do what no other agency can do, namely, to stop wars, they can do this only by destroying or immobilizing the fighting men. They may therefore be more serious enemies than the human adversaries against which armies strive. Military necessity has spurred men on to battle with them with an energy and an ingenuity which their peace-time menace to our industries and food supplies has not yet evoked. During the 1939–45 war especially, necessity forced us to a richness of invention which has made that distressing period one of the greatest in the annals of science. If so much benefit to the human race has come from the parasite's challenge to our ability to make war, how much more might come to us if we took up, with equal energy and speed, its challenge to our food production (see ENDEAVOUR, **7**, 27, 1948) and industrial capacity.

The cultivation of algae

E. G. PRINGSHEIM

The growing of pure algal cultures no longer presents the great difficulties formerly encountered, owing to recent improvements in technique. On the one hand it has resulted in new advances in plant physiology, especially in the study of photosynthesis, in ecology, and in the development of new forms of bio-assay. On the other hand, the large-scale cultivation of algae, although still in its infancy, may assume considerable practical importance—for instance, as a source of food. Dr Pringsheim explains the value of maintaining pure algal strains.

The culture of algae dates from some seventy years ago. It was not an individual contribution to botany, but developed from various sources. Observation of material kept in the laboratory without special apparatus, the use of nutrient solutions as employed in the study of higher plants, and the application of the methods of bacteriology, all had their share in the evolution of a technique for obtaining a healthy growth of algae under artificial conditions.

The most important step was the isolation of the species to be cultivated, culminating in the elimination of all other organisms, so that pure cultures resulted. This isolation is valuable, inasmuch as it brings us nearer to a complete control of conditions. Pure cultures are, however, neither always necessary for achieving valuable results, nor an end in themselves. In order to reap every possible benefit one has to employ synthetic, completely defined media, and to follow with the help of analytical methods their alteration by the metabolism of the growing algae.

Until recently, cultures of algae were believed to be useful and necessary for physiological investigations only. Even so, the application of bacteriological methods and media, without sufficient adaptation to the needs of the algae, entailed some reverses, since it not only excluded the vast majority of algae, but forced unnatural conditions even on those which could be grown. The field algologist could not make much use of such a technique, which distorted the shape of the organisms, and he therefore discarded cultivation altogether. The methods, imitating those successfully used with bacteria and fungi, combined in one manipulation the provision of food and the isolation of single individuals by using nutrient agar media, so that the individuals could multiply to form homogeneous colonies. The isolation of algae is, however, not as easy as that of most bacteria and yeasts. In the material used for inoculation, the number of algae is much smaller than that of contaminating organisms, and the agar used for fixing the individual algae in their places, and separating them from others, also favours these contaminants. Many are apt to spread over the substratum, frequently frustrating the efforts at isolation.

It was therefore necessary to divide the manipulation into two steps: first, mechanical isolation, and then the transfer into conditions favourable for multiplication. While formerly those algae were isolated which grew best in the medium—and only when one species predominated from the beginning was it possible to proceed more systematically—we now begin by choosing under the microscope the species which we intend to grow, and transfer it into a sterile fluid. In the majority of cases, the best way to isolate an alga is to suck it into a glass capillary, and then to blow it out, by means of a rubber cap. With this technique, it has become possible to analyse a complicated mixture of species by transferring each of them into separate culture vessels.

Full advantage of this mechanical separation is, of course, gained only if the isolated individuals are given suitable conditions for multiplication, and for this purpose a consideration of their ecological requirements is needed. Species from deep lakes, and other waters with a low concentration of nutrient substances, are best grown in very dilute solutions of inorganic salts containing all the essential chemical elements. Those from shallow, and more or less polluted, waters need a greater amount of nutrient substances than can be dissolved in an aqueous medium. In the natural habitat of such algae these substances are mainly supplied from the underlying deposits of mud. In cultures they can be provided by adding a little soil to replace the partly organic substances contained in mud. Previous heating destroys the competing micro-organisms contained in every soil, but no autoclaving is allowable, for this greatly impairs the suitability for growth. Many variations of the technique are possible, imitating the natural conditions, and almost all algae can now be grown in culture.

The result of such culture experiments, if successful, is a plentiful and healthy homogeneous algal material from which further cultures, completely free of other organisms, can be derived. We are not yet able to satisfy in pure culture the requirements of every algal species in respect of pH, chemical elements, and vitamin requirements. There are many species which thrive in soil-water cultures but cannot yet be grown in bacteria-free media, so that we are only at the beginning of a still wider development in the cultivation of algae.

In nature, biological communities are always mixed, and this renders unavoidable the interaction of various organisms. It will therefore never be possible to draw a true ecological picture by concentrating on a restricted number of taxonomic groups—for instance, bacteria and fungi—leaving algae and protozoa out of consideration. It is just because of this necessity to fill the gaps, in order to come nearer to a real general microbiology based on ecological knowledge, that the methods of growing algae (and also flagellates and ciliates) have yet to be improved.

The programme of culture research on algae is theoretical as well as practical. A few of the tasks will be indicated. Some are general problems which can best be tackled by using algae, others are problems related to algae specifically. If, for instance, the osmotic organization of plant cells is to be investigated one may, among others, consider the large cells of *Hydrodictyon*. If, however, the formation of the swarmers of *Hydrodictyon*, and the way these arrange themselves to form daughter nets, is to be studied, no other material can be used. In both cases it is most useful to have the alga available in a healthy state throughout the year. Too often it has happened in the past that such investigations came to a premature end because the material was no longer to hand.

Algal cultures are already widely used in Britain for teaching purposes. The species generally required are kept constantly in stock in good condition. Universities and schools soon grasped the advantage of having available at short notice most of the forms they required.

An outstanding example of the use of algae in research is in the study of photosynthesis, a field of the greatest importance because the chlorophyll system of plants is practically the only apparatus for supplying the organic substances essential to life. At last, too, chemists and physicists have joined physiologists in research on photosynthesis, and the progress already achieved is immense. Algae are the objects of choice for this work, as they provide a homogeneous and easily handled cell-material. Again, algae are not only, for many purposes, better suited than other green plants, but the peculiar photosynthesis of certain algae attracts the attention of physiologists. While the pigment system of most green algae is the same as that of flowering plants, ferns, and mosses, there are also groups with different pigments—for instance, the red and brown algae. The results obtained with these various groups show certain differences in behaviour which have thrown new light on basic problems.

For investigating these pigments and their physiological properties, one had until recently to rely on occasional natural mass production. Harvesting was not easy, and the admixture of other algae with different pigments was unavoidable. Mass cultures, first of modest dimensions, but now already on a large scale, provide the answer to these difficulties. The cultures will also make available other contents of algal cells—for instance, peculiar (possibly precious) oils, little-known sugars and polysaccharides, and new vitamins. Optimists even expect a valuable contribution to our food resources, and believe that such schemes could soon be practicable and economical.

In comparing the quantity of organic substances photosynthesized by traditional crops and algae respectively, and leaving apart the food value for human beings and livestock, one comes to figures of the same order of magnitude. In both instances only up to 1 per cent. of the light-energy is utilized, so that the scope for improvement is considerable.

In any case, production is generally limited not so much by the inner nature of the photosynthetic system as by external factors. It appears that a warmer and sunnier climate than that of Britain, as found for instance in the West Indies, would be essential for success. On the other hand, carbon dioxide fertilization, from which much may be expected, is feasible only in industrial areas where this gas is produced in excess of other needs. Artificial illumination is under present technical conditions largely restricted to experimental purposes, and is expensive.

In order to make the production of vast masses of small algae really feasible, much more knowledge of their nutritional requirements for profuse multiplication is needed; this could then be used to apply an improved technique on an ever increasing scale. Chemicals which are useful and cheap enough for experiments up to a certain size may not be available, pure, in sufficient quantity for mass production, and impure materials may be toxic. Many unforeseen difficulties are certain to arise if no proper preparatory study has been undertaken.

The difficulties which can be foreseen are: invasion by other organisms, obstacles to the continuous preservation of the cultivated algae in a healthy state of growth, efficient harvesting, and the choice of the most suitable algal forms. The last question depends much on what is expected from the algal crop. *Chlamydomonas* and *Tribonema*, used in Germany (Göttingen, Essen), are valuable for fat production. If carbohydrates or proteins are wanted, other algae may be more suitable.

In America the centres of investigation are in Chicago, Stanford (California), and Austin (Texas). Not enough has been published yet to judge the progress. Neither in Britain nor in other countries does any large-scale work seem to have been done. It is much to be regretted that no initiative has been taken in Britain. We cannot afford to wait until others are far advanced.

It is already evident that the nutrient mixtures of inorganic salts habitually employed are not in every case sufficient to support continuous growth, but that certain additional chemicals, in very small concentrations, are also required. It is not easy to supply them in the optimum concentrations, which are affected by mutual precipitation, and by the uptake in algal metabolism and the changes of *p*H connected with it. Furthermore, the maximum rate of multiplication can, in many instances, not be attained at all in inorganic solutions under controlled conditions, owing to the slow synthesis in the algal cell of indispensable organic compounds. The rate of growth is much increased by the addition of such substances, which are called growth factors.

In nature, these growth factors are produced by other organisms; they play an important part in the mutual relationship between the members of an ecological community. The sudden appearance or disappearance of an organism seems often to be caused by an alteration of the equilibrium between the members of the community. It is possible to show experimentally that substances produced by bacteria and fungi favour the growth of certain algae. In other instances the influence is deleterious, either owing to competition for nutritive substances, or to the production of toxic compounds which are called antibiotics. Whether algae themselves produce antibiotics is still controversial. That they may contain toxic substances is known in the case of certain *Myxophyceae* and *Cryptomonadineae*.

A favourable influence on one organism is also often exercised by another one in the production of nutrient substances; an organism may lack the enzyme to split a molecule into compounds which would provide it with food. The breakdown of proteins is, for instance, in nature generally divided into consecutive steps in which several micro-organisms may be involved. Algae often benefit from one of the intermediate products, and may multiply suddenly in a surprising way when such substances are supplied. Similarly, polysaccharides are decomposed, especially anaerobically in the bottom deposits of quiet waters, giving rise to substances which favour the development of many algae. On the whole, hexoses do not play so great a role as was attributed to them by earlier workers. Fatty acids, especially acetic acid, are more generally formed and available to algae, and are readily metabolized.

In cultivation, those algae which have been shown to grow better in the presence of organic substances can usually be caused to thrive by the addition of yeast extract and similar mixtures. In the elucidation of vitamin requirements one must depend on chance as long as no strictly synthetic media are available. Such media should contain every ingredient as a known chemical individual, so that the composition of the whole solution can be readily controlled. Still further ahead lies the ideal nutrition experiment, in which the fate of single substances inside and outside the living cell is followed up. For an approach of this kind, ordinary chemical methods will not always be sufficient; to supplement them, physico-chemical tests—for instance, those which use 'tracer' chemical elements (e.g. carbon, phosphorus)—are now available. Pure culture material of algae is indispensable.

Organic compounds are generally utilized only by algal species occurring at places rich in decaying matter, e.g. a great many flagellates and other unicellular algae. The majority of the higher forms have to rely on those organic compounds which are provided by their own photosynthesis. The differences are decisive for the ecological standards of the various algae. It is, however, not safe to reverse the reasoning, and to draw conclusions as to the physiological properties of the species from the state of the place where they are

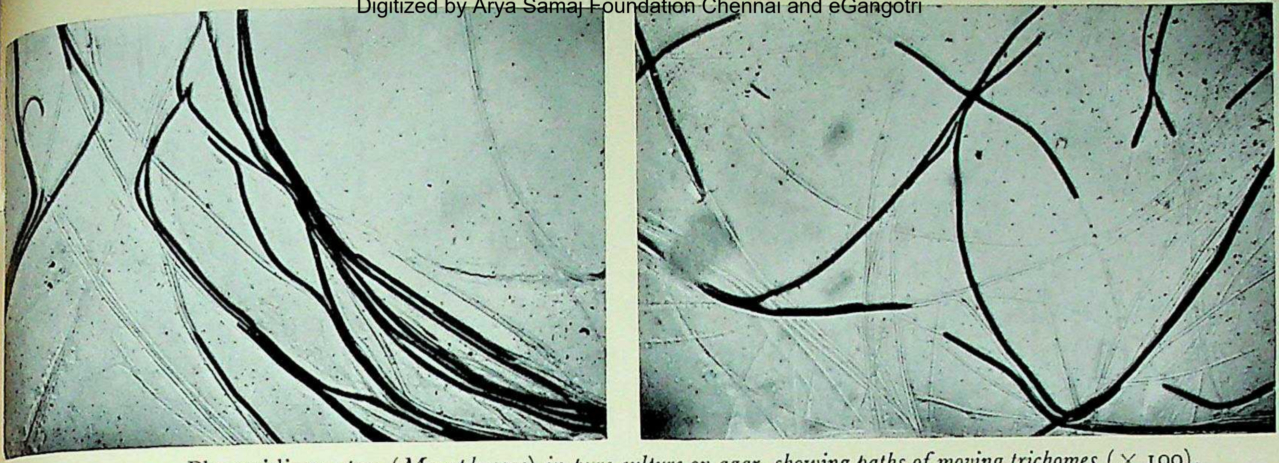


FIGURE 1 – Phormidium *spec.* (*Myxophyceae*) *in pure culture on agar, showing paths of moving trichomes* (× 100).

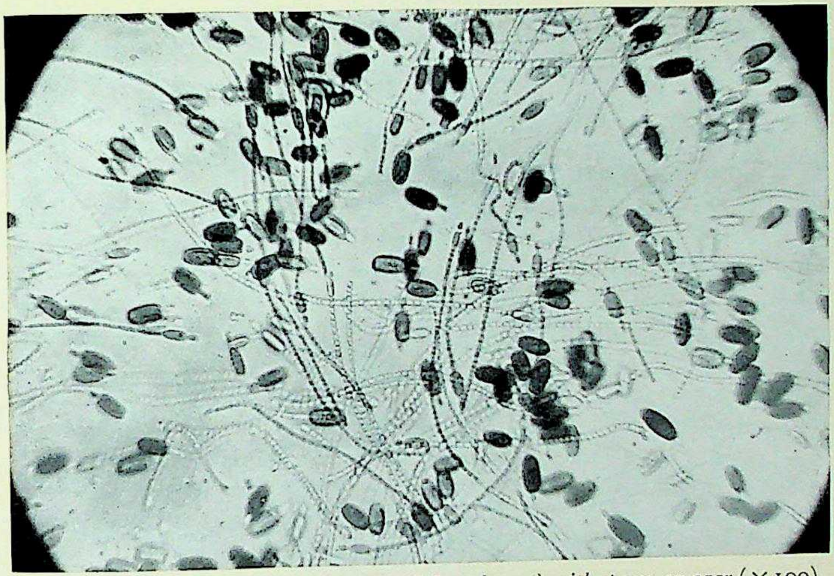


FIGURE 2 – Cylindrospermum *spec.* (*Myxophyceae*) *with spores, on agar* (× 100).

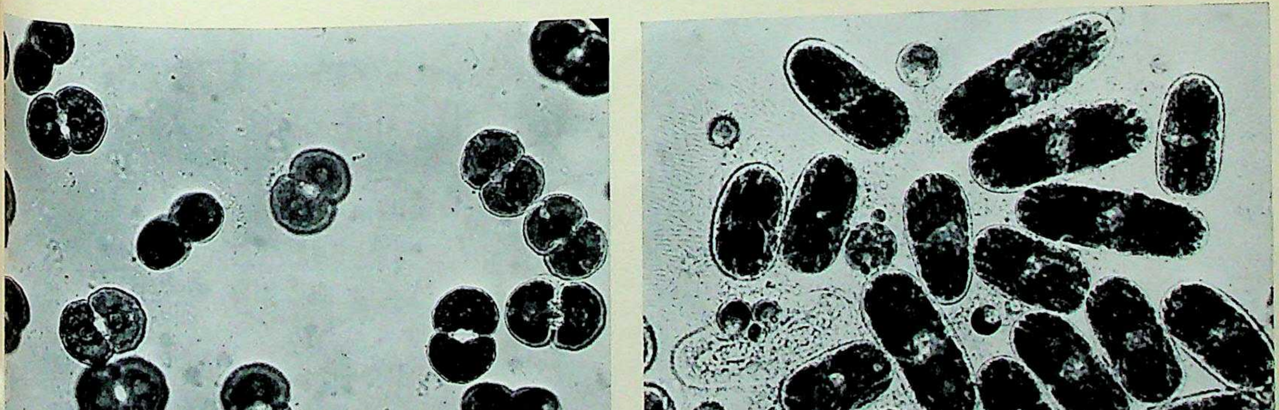
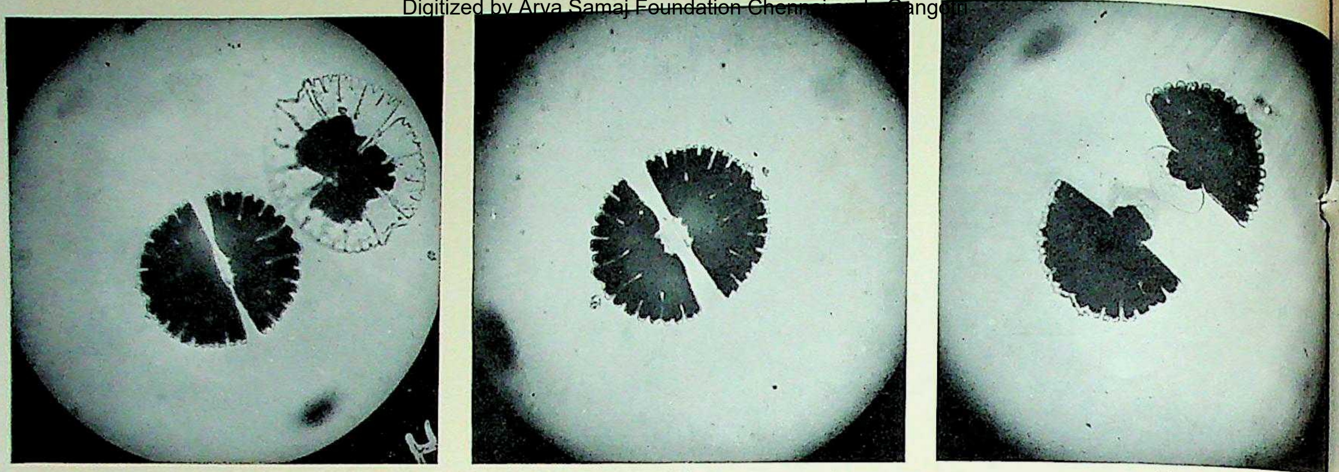
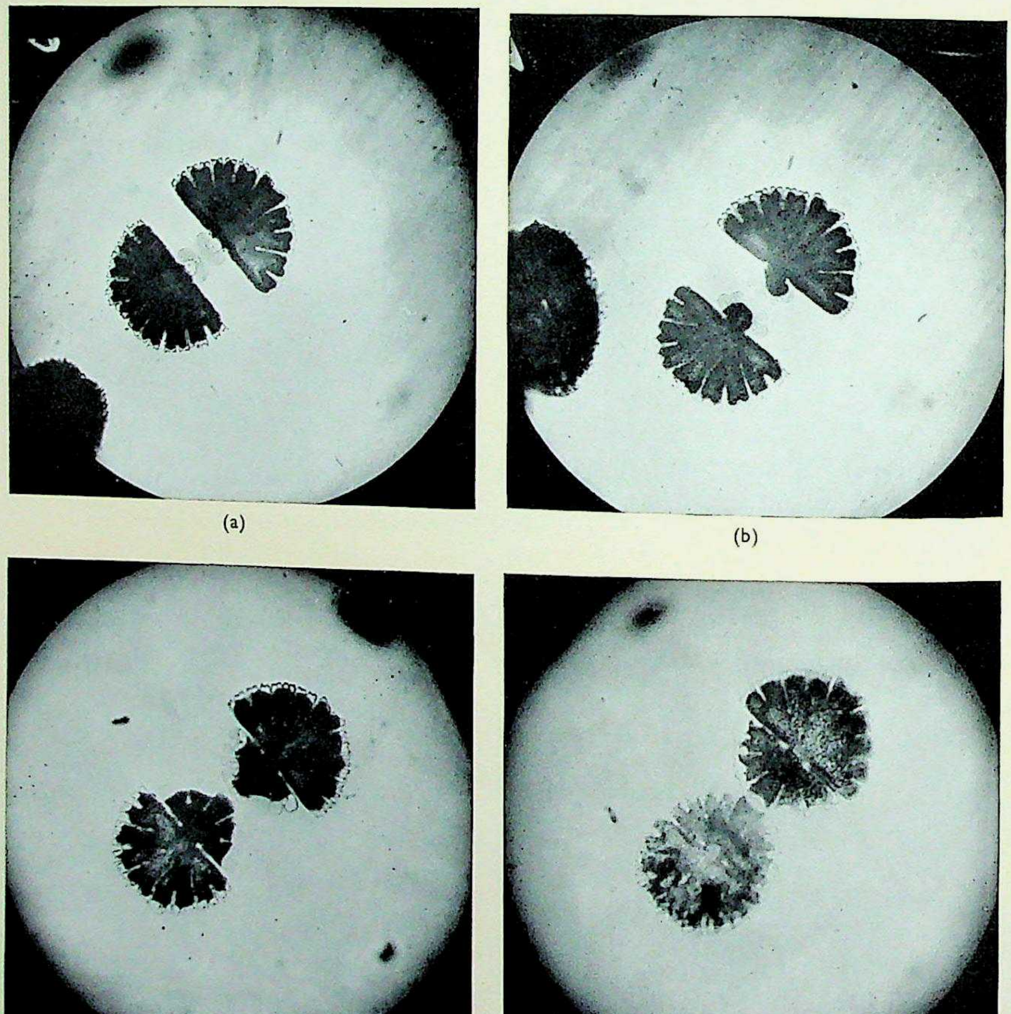


FIGURE 3 – (*Left*) Cosmarium laeve (*Desmidiaceae*) (× 300) *and* (*right*) Cylindrocystis Braunii (*Mesotaeniaceae*) *in pure culture on agar* (× 300).



(a) (b) (c)

FIGURE 4 (a–c) – Micrasterias rotata (*Desmidiaceae*); *three stages of cell division; culture material;* (a) 17·03, (b) 18·11, (c) 20·03 o'clock (× 100).



(a) (b)

(c) (d)

FIGURE 5 (a–d) – Micrasterias denticulata (*Desmidiaceae*); *four stages of cell division; culture material;* (a) 10·03, (b) 10·50, (c) 12·12, (d) 14·08 o'clock (× 100).

found. Algae which live in dirty water may still be unable to make use of the organic substances within easy reach. Only cultural experiments can decide the issue. Even when a species is decidedly favoured by certain organic compounds, this need not be caused by their utilization, if other organisms are not excluded. Thus *Polytoma* and *Polytomella* were once believed to be sugar-flagellates, whereas in fact they live on fatty acids.

Algae are often the main food of animals and their larvae. To learn more of their conditions of life, and the way they are taken in and consumed, is a matter of urgency in the efforts to grow more food in rivers, lakes, and even the sea. It is already known, e.g. from experiments in the United States, and in Bohemia and France, that the productivity of fish-ponds can be substantially improved by addition of fertilizers, but that the process has to be watched carefully and adjusted to the kind of fish to be reared. On the other hand, algae may cause serious trouble in waterworks, in small fish-ponds, and even on the soil of commercial gardens and on house walls, so that the need for algicides is obvious.

During the last few decades it has become increasingly obvious that descriptions of many algae were built on a very insecure foundation. This is not so in every group, but there are a number of the simplest as well as of the more complicated families, all commonly occurring, where the degree of variability cannot properly be estimated without culture experiments. Differences in two samples of natural material of the same alga may be due either to hereditary features, or to modification by the conditions of life in the habitat. If the whole population is modified in the same way, it may easily be mistaken for a different taxonomic unit. This has often happened in members of the *Euglenineae*. In many Chlorococcaceae the formation of colonies has been used as a characteristic of genera and even families. It is not possible to do without colony formation as a taxonomic characteristic. Cell-structure and reproduction do not suffice to differentiate the many species of the Chlorococcales. The same species may occur as isolated cells, as colonies of four to sixteen cells, or as compound colonies comprising many such groups in a more or less regular arrangement. Again, only culture experiments can decide which forms belong to one species, and under which conditions the cells remain united after division. It is quite possible, for instance, that certain species of *Ankistrodesmus*, *Quadrigula*, and *Tetradesmus* are all the same, although at present grouped in different families. Among the more highly organized algae, *Cladophora*, with its many species and innumerable varieties and forms, is an example of the inadequacy of merely morphological investigations for settling taxonomic problems. If we cannot recognize species, it is useless to attribute to them definite physiological and ecological properties.

Whereas culture research is in the first instance useful to describe species more thoroughly, and to determine their range of modification, we shall no doubt soon hear more about algal genetics. In spite of interesting beginnings, a well-organized approach has not yet been made. It was not by chance that F. Wettstein decided to use mosses for his masterly genetical studies, and discarded algae. Among the latter are, so far, few in which sexual reproduction can be induced at will, and there remains the great obstacle that sexually-produced resting-stages cannot be made to germinate with certainty. This was the reason why Mainx's promising experiments on species of *Oedogonium* could not be pursued far enough to give the results he hoped to obtain. A better technique will overcome these difficulties.

For most of the above-mentioned investigations, suitably equipped laboratories are required, in which cultures of algae can be regularly maintained. Collections exist at Geneva, Bâle, and Cambridge (England), and on a smaller scale in Paris, Prague, and Uppsala, and at various American laboratories. Most of them are kept by specialists for their own use only. None of them has an assured future, except to some degree that at Cambridge, for which the university took responsibility. Yet it is all-important to preserve the strains used in standard investigations, for further research and comparison.

For these reasons, international co-operation is needed to establish at least one specially built and equipped laboratory of experimental algology as a centre for the various lines of research, and as a source of cultures and advice. It should also be willing to demonstrate methods to inquirers. How necessary such a centre is, the writer knows from his own large correspondence. Its role cannot be played satisfactorily by any of the stations at present devoted to algal research, owing to their narrow restrictions in extent and means, while physiologists, biochemists, and others cannot be expected to acquire the necessary familiarity with the algae and related small organisms without expert assistance. This difficulty will increase in the near future, and the time has come for improvement.

The development of enzymology

P. F. FLEURY and J. E. COURTOIS

Enzymes have been used in fermentation processes for thousands of years. Study of their mode of action has revealed their vital role in intermediary metabolism and an intimate connection exists between them and certain vitamins and chemotherapeutic agents. There is indeed scarcely any constituent of living cells which is not associated in its production and decomposition with some enzyme system. In clinical medicine, determination of enzyme levels in the blood has become of considerable diagnostic value.

Research on enzymatic reactions began in the eighteenth century, when Réaumur, and afterwards Spallanzani, observed that the gastric juices dissolved meat. In 1814, Kirchhoff pointed out that the germinated seeds of barley contained a substance able to convert into sugars not only the starchy matter of the grains themselves, but a certain added quantity as well.

The separation of this substance, amylase—and thus the discovery of the first enzyme—was due to Payen and Persoz. On 17th June, 1833, they presented (through J. B. Dumas as intermediary) a communication to the *Académie Royale des Sciences*. They announced the separation from malt of 'a solid, white amorphous substance, insoluble in alcohol, but soluble in water and dilute alcohol. Heated at 65–70° C with starch granules, it possesses the remarkable power of quickly separating the envelopes from the transformed interior substance, the dextrin. . . . This particular property of separation has decided us to give to the substance that possesses it the name of diastase, to express precisely this fact.'[1]

In a wider sense, the name of diastase was for a long time given to other substances of similar properties, but gradually the term enzyme (Greek 'in yeast') was substituted for it. However, the use of the suffix 'ase' was established in the nomenclature of enzymes (amylase, phosphatase, etc.).

The original paper of Payen and Persoz mentions some properties of diastase that were later found to be fundamental characters of enzymes: (*a*) the thermolability—'If the solution of diastase is heated to boiling, it loses the power of acting on starch and dextrin'; (*b*) the considerable disproportion between the quantity of enzyme introduced and that of the transformed substrate—'When the extraction of this new immediate principle is made carefully, its activity is such that one part by weight is sufficient for rendering soluble in warm water the contents of 2000 parts of dry starch granules, and transforming the dextrin into sugar'; (*c*) the possibility of purifying the diastase by precipitation with alcohol from its aqueous solution. Incidentally, to the end of the last century this precipitation remained the principal method of purifying enzymes.

Between the discovery made by Payen and Persoz and the present time, three chief periods can be distinguished in the development of our knowledge of enzymes: the stage in which the notion of an enzyme was formed and defined, the stage of generalization, and the stage of the considerable expansion marking the last twenty years or so.

CONCEPTION OF THE IDEA OF AN ENZYME (1833–94)

From 1835 onwards, various workers noted other products possessing the characteristics of diastase, but acting upon different substances; thus pepsin, emulsin, myrosin, trypsin, lipase, sucrase, and urease were successively discovered. In 1877, Duclaux, one of the ablest followers of Pasteur, published an article entitled *Action des diastases ou ferments solubles*. In a dozen pages Duclaux coordinated contemporary knowledge on the subject, and his article may be considered as the basis of the science of enzymology.

GENERALIZATION OF THE IDEA OF ENZYMES (1894–1926)

All the enzymes discovered up to this time were hydrolases, i.e. enzymes decomposing the substrate by hydrolysis, the H and OH groups of the water attaching themselves to the ends of a broken valency bond. It was thus an important advance when, in 1894, E. Bourquelot and G. Bertrand discovered a new class of enzymes, viz. the oxidases, able to add not water but oxygen to the substrate.

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[1] From the Greek word *diastasis*, which means 'separation.'

The study of oxidases led G. Bertrand to suggest the first conception of the constitution of enzymes, a conception which, slightly modified, is now universally accepted. It is as follows. The entire enzyme or holoenzyme is built up of at least two fractions:

(*a*) The apoenzyme, which is always a protein; it is colloidal and thermolabile.

(*b*) The co-enzyme, of variable chemical constitution, frequently a phosphoric ester and sometimes a metallic derivative; very often the co-enzyme, which is non-colloidal, is fairly thermostable.

The discovery of a non-hydrolysing enzyme was quickly followed by that of other enzymes distinct from hydrolases. By compressing yeast Buchner, in 1897, obtained a liquid which converted glucose into carbon dioxide and ethyl alcohol; this preparation, zymase, had the character of an enzyme but catalysed a reaction that had never before been effected except by living yeast cells. This discovery went far to fill the gap that was supposed to exist between 'organized ferments' and enzymes.

In 1902, Schärdinger described the first dehydrogenase. This enzyme, present in milk, removes hydrogen from water, and the hydrogen can be taken up by methylene blue, which is thereby reduced to the colourless leuco-base. About the same time, Neuberg discovered carboxylase, which converts pyruvic acid into acetaldehyde and carbon dioxide. All the enzymes so far isolated catalysed only degradation reactions, but, between 1900 and 1912, it proved possible after many attempts to catalyse various condensation reactions enzymatically. The researches were principally directed to the biosynthesis of holosides and heterosides, and were carried out by Croft-Hill, Bayliss and Armstrong, Bourquelot, Hérissey and Bridel, and others. Finally, in 1906, a fundamental discovery was made by Harden and Young, who observed that, in alcoholic fermentation, sugar is first transformed into a diphosphoric ester of fructose. The isolation of intermediate compounds of glycolysis, and the researches made at the same time by Hopkins on lactic acid in muscular contraction, constitute the beginning of those studies on intermediary metabolism that were to develop so fruitfully in Britain.

DEVELOPMENT OF ENZYME CHEMISTRY (1926–50)

At the end of the second period, enzymes were viewed as specific thermolabile catalysts, but none of the basic problems they set—isolation in the pure state, constitution, specificity, mode of action—had been resolved. The period from 1926 to the present day has been marked by great advances in these different domains.

It was inaugurated in a spectacular way by the work of the American school. In 1926, James Sumner described the separation of urease in the crystalline state. Jack-bean flour is extracted with water, and the solution is treated with acetone; on cooling, crystals are deposited, the ureasic activity of which is not sensibly modified by further crystallizations. These crystals of urease resemble the globulins in composition and general properties.

This important discovery was the starting-point of a long series of researches that yielded important data on the chemical structure of numerous enzymes.

PURIFICATION OF ENZYMES

Holoenzymes have the character of proteins, so that enzymology has gained much by advances realized in the purification of proteins. The principal current methods of purification are fractional precipitation by salts (e.g. ammonium, sodium, and magnesium sulphates, alkaline phosphates); precipitation by organic solvents miscible with water (methyl alcohol, acetone, dioxan); and adsorption (e.g. with alumina) and elution. To these chemical methods, physical methods may be added, e.g. dialysis under different conditions, particularly electro-dialysis; ultrafiltration; and differential electrophoresis. It should be noted that these methods yield very active preparations but not necessarily pure holoenzymes in the chemical sense. The most active preparations obtained, even when crystalline, almost always contain an associated fraction devoid of enzymatic activity.

The separation of enzymes of very distinct specificities is relatively easy—a classic example is that of the enzymes in the pancreatic juice: proteases, amylase, and lipase. On the contrary, it is very difficult and sometimes almost impossible to separate enzymes of very near specificities, e.g. the glucidases of almonds or phosphatases of seeds (J. Courtois). Indeed, enzymes transforming substrates of similar chemical constitution have in common numerous physico-chemical characters that make their separation very difficult without denaturation of the protein apoenzyme. An important outcome of the availability of enzymes in an advanced degree of purity has been the elucidation of the chemical structure of different co-enzymes.

CHEMICAL CONSTITUTION OF CO-ENZYMES

It is possible by dialysis to separate from Buchner's zymase a thermostable substance, cozymase, which is the co-enzyme of numerous dehydrogenases. From 1920 on, von Euler and Myrbäck endeavoured to purify this co-enzyme, and, about 1930, they showed that it is a nucleotide containing adenine. In 1934, von Euler on the one hand, and Warburg and Christian on the other, isolated nicotinamide from the co-enzymes of dehydrogenases, and shortly afterwards biochemists identified this substance with vitamin PP (pellagra-preventing).

In the same year, Theorell proved that the "yellow enzyme" hydrogen carrier from yeast can be separated by dialysis into its apoenzyme and coenzyme. The yellow enzyme is reconstituted by reunion of these two fractions, but—a new fact of essential importance—the co-enzyme was identified with a phosphoric ester of riboflavin, the vitamin B_2. For the first time, a connection was established between enzymes and vitamins.

In 1935, Lohmann and Schuster showed that co-carboxylase is a phosphoric ester of vitamin B_1: this fact confirmed the work of Peters and his co-workers at Oxford, who had already shown that vitamin B_1 intervened in the metabolism of pyruvic acid. In the table (p. 147) is given a list of vitamins forming part of certain enzymes; it will be noted that in some cases holoenzymes of distinct specificities have the same co-enzyme. Co-dehydrogenase I (co-zymase) is the co-enzyme of a number of distinct dehydrogenases acting respectively on diphosphoglyceric aldehyde, lactic, malic, α-glycerophosphoric, β-hydroxybutyric, and formic acids, glucose, some acyclic alcohols, etc. Other similar facts tend to show that in diastatic reaction the apoenzyme plays an essential part, since it seems to guide the specificity of the co-enzyme.

It is rather remarkable that in almost all co-enzymes, the vitamin, an essential metabolite, is joined more or less directly to phosphoric acid. Courtois and Barré supposed that this esterification of a hydroxyl radical by phosphoric acid tends to favour the union of the metabolite with the corresponding apoenzyme, this union being effected with the other acid groups of the phosphoric acid. Courtois and Barré observed that a vegetable protein, conamandine, could form insoluble compounds, at about pH 3·0–4·0, with numerous phosphoric esters, and pyrophosphoric and orthophosphoric acids. Esters of cyclic hydroxy-compounds give the most stable combinations.

A very important development in enzymology is the notion of antimetabolite. In 1940, Woods found that *p*-aminophenyl sulphonamide,

$$NH_2\text{-}C_6H_4\text{-}SO_2NH_2$$

has an opposing action to that of *p*-aminobenzoic acid, $NH_2\text{-}C_6H_4\text{-}CO_2H$. This *p*-aminobenzoic acid is an essential metabolite, necessary to the development of numerous micro-organisms; it seems to be combined in the form of still imperfectly known enzymes.

The sulphonamide having a chemical structure similar to that of this metabolite can displace it from its combination with the apoenzyme, and substitute itself to form a new compound without enzymatic action. Equilibrium between metabolite and antimetabolite sulphonamide is governed by the law of mass action; it depends on the respective concentrations of the two substances and on the stabilities of their combinations with the common apoenzyme.

This discovery represented the first contact between chemotherapy and enzymology. It explained the bacteriostatic action of sulphonamides, by assuming the formation of inactive combinations which substitute themselves for enzymes indispensable to bacterial metabolism. During recent years, other metabolites having a chemical relationship with vitamins acting as enzymes (sulphopantothenic acid, pyrithiamine, etc.) have been prepared. It is likely that some of them may be used in therapeutics, and chemotherapy may thus receive a new orientation.

The list of enzymes of accurately known constitution is not limited to those of which the co-enzymes contain vitamins and which have a certain similarity to nucleoproteids. Some enzymes show clear analogies to respiratory pigments; catalase and peroxydase are iron proteins rather similar to haemoglobin. In them, iron is joined to a tetrapyrrolic ring connected to a holoproteid fraction. The Cambridge biochemists Keilin, Mann, and Tissières, have shown that some oxidases are copper proteins somewhat similar to the haemocyanins, the respiratory pigments of molluscs and crustaceans.

Finally, various metallic ions can activate certain enzymes, and the activation becomes greater with greater purity of the enzyme. Such enzymes are said to possess a dissociable metallic constituent (J. Roche). It seems doubtful whether the

VITAMIN CONSTITUENTS OF CERTAIN ENZYMES

Vitamin revealed in holoenzyme	*Chemical structure of co-enzyme*	*Corresponding holoenzyme*
B_1 (thiamine)	Pyrophosphoric ester of thiamine	Carboxylase of α-ketonic acids
B_2 (lactoflavin)	Orthophosphoric ester	Yellow enzyme of Warburg
	Orthophosphoric ester bound to adenylic acid in the shape of dinucleotide	Second yellow enzyme *d*-aminoacid oxidase xanthine oxidase fumarate hydrase diaphorase aldehydedehydrases
B_6 (pyridoxine)	Phosphorylated pyridoxal	Decarboxylases of different L-amino acids transaminases
	Pyridoxamine phosphate	Glutamic and aspartic transaminases
PP (nicotinic acid amide)	Dinucleotide with nicotinic acid amide-ribose-$(PO_3)^n$-ribose-adenine $n = 2$-codehydrase I $n = 3$-codehydrase II	Varied dehydrogenases of different specificities
Pantothenic acid	Co-enzyme A (phosphoric ester ?)	Enzymes of acetylation and conjugation
Inositol	?	Certain amylases (Williams) absent in other purified amylases (Fisher and Bernfeld)
F (pteroylglutamic or folic acid) ..	?	Enzymes oxidizing tyrosine in liver
H′ (*p*-aminobenzoic acid)	Peptide ?	Imperfectly defined enzymes taking part in bacterial intermediary metabolism

metallic ion is the co-enzyme. It may serve either to promote the union of enzyme and substrate, or to stabilize the union of apoenzyme and co-enzyme. Thus manganese activates arginase, magnesium enolase, and magnesium (and, to a smaller degree, zinc and cobalt) alkaline phosphatases. This participation of metals in enzymatic reactions provides an explanation of the biochemical role of trace elements, i.e. elements normally present in tissues in very small quantities (G. Bertrand).

Knowledge gained in the last two decades must not make us forget that the constitution of several hundred enzymes is as yet quite undetermined.

ROLE OF ENZYMES IN INTERMEDIARY METABOLISM

For about a century, enzymes were thought to operate independently of one another, but a thorough study of intermediary metabolism has shown that the reactions occur in a series of stages, and that in each stage a new enzyme plays its part. Every enzyme transforms a metabolite which has arisen in the preceding stage from another enzymatic action. At present, the best-known intermediary metabolism is that of glucose (alcoholic fermentation and muscular glycolysis). During these processes, energy contained in the molecule of glucose is degraded progressively by a chain of reactions successively catalysed by phosphorylase, phosphoglucomutase, hexokinase, phosphopherase, zymohexase, triosephosphate isomerase, a first dehydrogenase, phosphoglyceric acid isomerase, enolase, another phosphopherase, a second dehydrogenase, and so on.

Energy produced in certain reactions catalysed by enzymes can be accumulated for a time in certain intermediary substances such as Lipmann's strongly bonded phosphate compounds.

These complex reactions (scission, isomerization, transfer) are sometimes accompanied by a process of re-synthesis. One of the best-known enzymes of those endowed with the power of synthesis is the phosphorylase of the Coris. It catalyses the reversible reaction: n-glucose-1-phosphate $\rightleftarrows$ polyholoside with n glucose $+$ n orthophosphate. With the phosphorylases of animal origin the polyholoside synthesized resembles glycogen; with vegetable phosphorylases, located more specially in amyloplasts (Yin and Sun), a starch-like substance is obtained. By use of enzymes of the same type, sugars such as sucrose have been obtained by biosynthesis.

We shall next point out the importance of pherases. These enzymes catalyse the transference of a radical or grouping from one compound to another; they are essential in intermediary metabolism. Ten years ago, Braunstein described the aminopherase or transaminase that carried, reversibly, the amino group from an α-aminoacid to an α-ketonic acid, as, for example, in the reaction: L-glutamic acid $+$ pyruvic acid $\rightleftarrows$ α-ketoglutaric acid $+$ L-alanine. The Krebs tricarboxylic acid cycle is another example of these chain transformations. Up to the present, however, we are familiar only with fractions of different chains.

These researches accentuate the narrow specificity of action of enzymes. Solution of this still unsolved problem may probably be achieved by the same methods as that of the parallel problem of the specificity of antigens and antibodies.

PATHOLOGICAL VARIATIONS OF ENZYME ACTIVITY

For some ten years, determination of the activity of certain enzymes has been a routine practice in clinical biology. The pathological changes observed facilitate diagnosis, and a progressive return to a normal value is a sure indication of the efficacy of a therapeutic treatment.

We shall give some of the most characteristic examples. H. D. Kay of Reading showed that the activity of serum phosphatase in an alkaline medium is related to the functioning of the skeleton; the normal values are higher in young individuals, with the skeleton still developing, than in adults. The activity of serum phosphatase increases notably in various bone diseases, e.g. osteitis, rickets, osteomalacy, osteosarcoma; its return to a normal value is a reliable test of recovery. Serum also contains, in smaller proportions, a phosphatase reacting in a slightly acid medium, and the activity of this phosphatase considerably increases in cancer of the prostate with metastases. Recovery, full or partial, of the patient is accompanied by a progressive fall in activity.

The activity of different esterases of serum (tributyrinase, cholinesterase, procainesterase) is related to the state of the liver; determinations of it furnish a very useful factor in the diagnosis of hepatic affections. During acute pancreatitis a large overflow of amylase into the serum is observed; the excess of enzyme diffuses into the urine, where it can be detected. The activity of hyaluronidase is related to fertilization, and to certain diffusion phenomena in mucous membranes.

CONCLUSIONS

For more than a century, advances in enzymology have equalled those made in other, perhaps more spectacular, branches of biochemistry and biophysics. Enzymology represents, in some ways, a cement that unites these branches, which the progress of science and the resulting specialization tend to separate. It is, however, evident that, more than a century after the discovery of Payen and Persoz, the study of enzymes has not yet brought a satisfying solution to all the problems raised. Moreover, many new problems, of the most varied types, continue to arise—but is not that the symptom of full vigour in a science?

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Cavitation in liquids

E. G. RICHARDSON

Research on the impact of solid bodies on liquids, and on the cavitation resulting from the movement of such bodies through liquids, begun half a century ago as an academic study, has assumed great practical importance. It plays a part, for example, in the design of ships' propellers, in the study of certain types of metallic corrosion, and in the application of some ultrasonic techniques. Dr Richardson here summarizes our knowledge of the subject.

In 1897 Worthington published a paper on the splashes produced by steel spheres, or by water drops, falling on to a plane water surface. Subsequently he published a number of photographs, taken by the then novel flashlight method, in a book called 'A Study of Splashes' One of these is reproduced here (figure 1) to show a feature of the low-speed entry of a solid sphere into a mass of liquid, i.e. the rise of liquid in the shape of a jet to form the splash behind the entering sphere. It illustrates the cavity, visible as a black tapering 'sock,' which has been formed by the entry of a 5 cm diameter ball dropped from a height of 9 ft. At this instant the ball itself has passed outside the picture below the field of view, which is limited by the white circle thrown on the plate by a light and lens behind the tank. The solid imparts a centrifugal impulse to the liquid, to leave a cavity into which the air rushes. Such cavities are also formed when a drop of liquid falls at sufficient speed into a mass of the same liquid, whether the latter is stationary or moving. Thus the scientific origin of the 'purling of the brook' of which the poet speaks is to be sought in the action of drops of liquid falling into the main stream, in so doing forming cavities which emit sounds of a frequency roughly in inverse proportion to their volume as the air is sucked in, and expelled again when the hole collapses.

This, the formation of hollow spaces behind a solid body entering a liquid, is one of the two aspects of cavitation which it is the purpose of this article to discuss. With the advent of the aeroplane, study of the impact of a solid body on a liquid became an urgent matter. The force on the body entering the liquid is due partly to the skin friction of the liquid moving over its surface up to the point when the liquid leaves it to form the cavity, and partly to the work done in imparting momentum to the liquid as the entering body clears a way for itself. If there is a pronounced splash, work is of course also done in imparting vertical momentum to the surface. In fact, however, most of the momentum has a horizontal or nearly horizontal direction. This can be seen if a number of tiny air bubbles are dispersed in the liquid just before the sphere enters, so that a rapid series of superposed photographs can show, by the tracks of the air bubbles carried with the liquid, the motion imparted locally to it. This is the technique developed by Schlichter; it is illustrated by figure 2, which shows a series of superposed photographs (taken by the Egerton stroboscopic camera) of the entry of a sphere into water, in which successive positions of individual air bubbles show the tracks of the local impulse given to the water.

The practical importance of such impact forces was realized when heavy seaplanes touched down on to the sea. Although such a 'landing' is oblique, and the craft does not penetrate the water far, yet a considerable cavity can be formed under these conditions, the creation of which may give rise to dangerous pressures on the float or hull structures. The magnitude of these forces was first investigated, both with small models and at full scale, at the Marine Aircraft Experimental Station of the Royal Air Force.

The other reason for studying the entry of bodies at high speed into water, and the shapes of the cavities they produce, is associated with belligerent attack on ships below the water-line.

Whether for peaceful or warlike objects, such water-impact studies are much too costly in time and material to be carried out at full scale except as a check on research with models, so that it becomes very important to know by what criterion the results obtained on a small scale are to be converted to full scale. The criterion by which most aerodynamic research is scaled is the well-known parameter of Osborne Reynolds, but when a liquid-gas surface is involved, as it is in this instance and in the motion of all surface craft, the viscosity which enters into the Reynolds number becomes unimportant, and the Froude number (involving the quotient of the square of the velocity by the linear dimension) becomes more significant.[1]

The writer has been able to show that all initial cavity-shapes formed by spheres entering liquids may be scaled on such a basis, and that the viscosity of the liquid plays little part. Thus, the sizes of the cavities formed by a sphere shot at equal speeds into water or into glycerol are the same. The only effect of viscosity in the latter is to delay the breakaway, and subsequent rise to the surface, of the entrained air. It can be shown that the relative density of the liquid to that of the atmosphere should, for correct scaling, be changed in proportion to the depth at which the cavity is observed, in order to conserve hydrostatic pressure. As such cavities do not extend to great depths, this correction is a minor refinement. Model dropping tanks have nevertheless been built in enclosed chambers in which the effect of reduced air pressure on the cavity may be investigated. Though there is no observable change in the initial shape of the cavity, it is noted that, by the return of the liquid, it seals up more often first at the surface when normal atmospheric pressure rules; if the atmospheric pressure is reduced to about one-fifth of normal there is a pronounced splash, the cavity remains open in bell shape at the surface, and the liquid seals first lower down in the cavity. Figures 3 and 4 show this difference: figure 3 is of an entry under atmospheric pressure after the cavity has sealed at the surface, and figure 4 shows two stages of a similar entry under reduced pressure, with the cavity flaring out at the surface and sealing midway. Surface tension has little effect at the entry speeds here considered, because the impact forces are large.

In aerodynamics we often hear nowadays of another parameter, i.e. the Mach number, when the speed of motion is comparable with that of sound in the medium. It is now readily possible to fire spheres into water at speeds approaching that of sound in water (1435 m/sec), and shock waves are then set up in the water, but the cavity produced conforms with those at a lower speed of entry (on a Froude number basis). Thus—fortunately—we do not need to trouble ourselves with Mach numbers in this branch of fluid dynamics.

Another type of cavitation is that which may be formed when a body completely submerged travels at such a high speed that a vacuous cavity is set up, or at least a region in which the pressure is reduced to the saturation pressure of the vapour of the liquid concerned. The term 'cavitation' for this phenomenon was due to Froude.

Cavitation is conditioned by the maximum tension, or negative pressure, which a liquid can tolerate before breaking up into 'lumps,' like a plastic solid pulled opposite ways. There has been much argument, based on both theory and practice, as to what this critical tension is. Berthelot, who first considered it, sealed up a nearly boiling liquid in a strong glass vessel and waited for breaks to occur in the continuity of the liquid as it cooled. From his experiments he estimated that water could stand 200 atmospheres before breaking up and leaving vacua in the tube. However, those who have repeated these and analogous experiments, with direct measurement of the critical tension, report much lower values, and Temperley thinks that a liquid can withstand only about ten atmospheres negative pressure.

Because the tips of ships' propellers move faster than other known submerged bodies, it was in this case that cavitation due to high-speed underwater motion was first noticed. The first water channel in which cavitation on propellers, driven by motors from outside the tunnel, could be studied was built by Sir Charles Parsons in 1910. His earliest experiments with cavitating model propellers in a tank of water were made at the beginning of this century. Out of them developed the tunnel, with the propeller submerged in a fast-flowing stream of water.

This kind of cavitation is closely related to that which we have already discussed. In both cases the liquid secedes from the body where the hydrostatic pressure on it falls practically to nil, so that there is no force to make the boundary layer of liquid adhere to the surface. Those shapes of bodies causing the largest acceleration of the fluid at sharp corners will cavitate at the lowest mean speeds of propulsion. Thus a disk with its axis in the direction of flow of the liquid will readily form a large cavity in the water behind it, similar to that on entry, if the special features of a free surface be excluded (figure 5). It must be remembered that the entry cavity can be formed at a much lower speed and is not a near vacuum, for, as we have remarked, it rapidly fills with air from the atmosphere above. Relative speeds of the order of 6 m/sec are required to produce the cavities behind a submerged object.

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[1] R. E. Froude was a pioneer British engineer, the first to make measurements of the resistance of model ships towed in a canal, and to correlate such measurements with full scale.

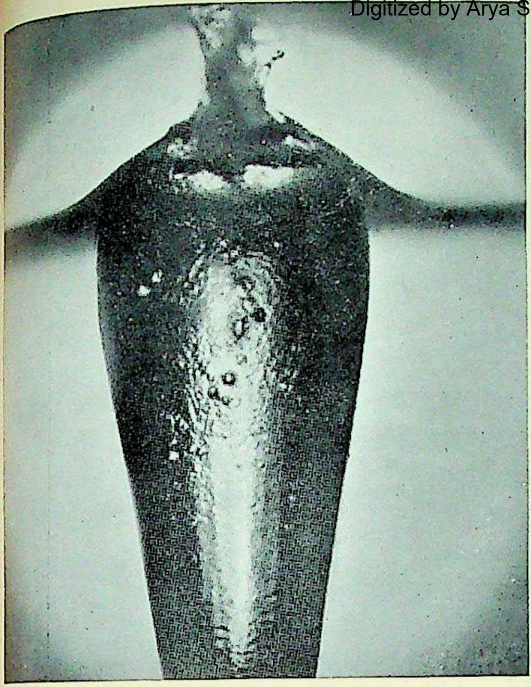

FIGURE 1 – *Entry of sphere 5 cm in diameter into water at a speed of 2 m/sec. (Worthington) (approx. full size)*

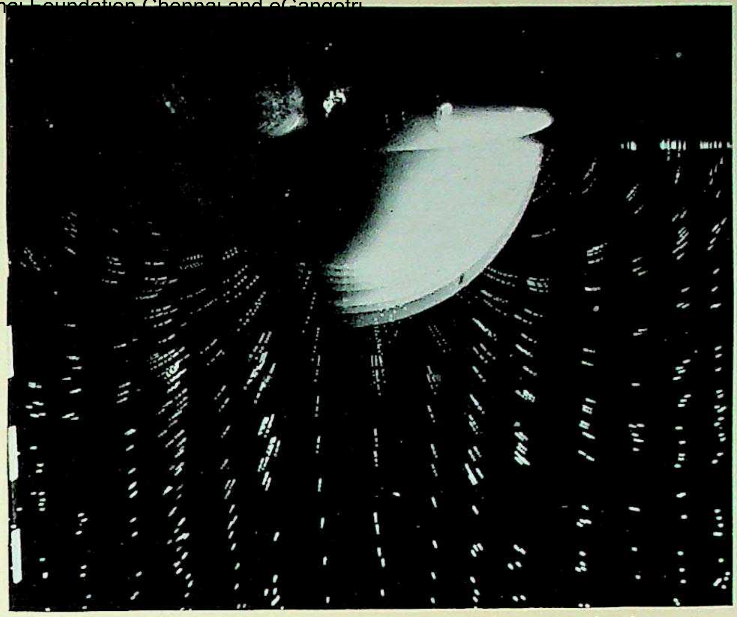

FIGURE 2 – *Streamlines of water disturbed by entry of sphere, the motion being shown by the traces of the air bubbles in the superposed photographs. (U.S. Navy)* (× 0.25)

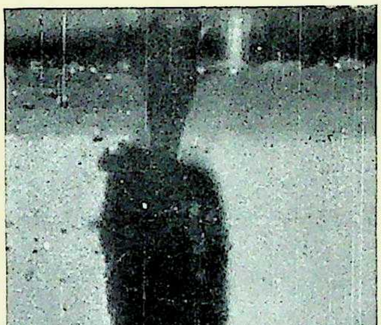

FIGURE 3 – *Entry of sphere 2·5 cm in diameter at 9 m/sec, showing 'surface seal' of cavity. (Reduced)*

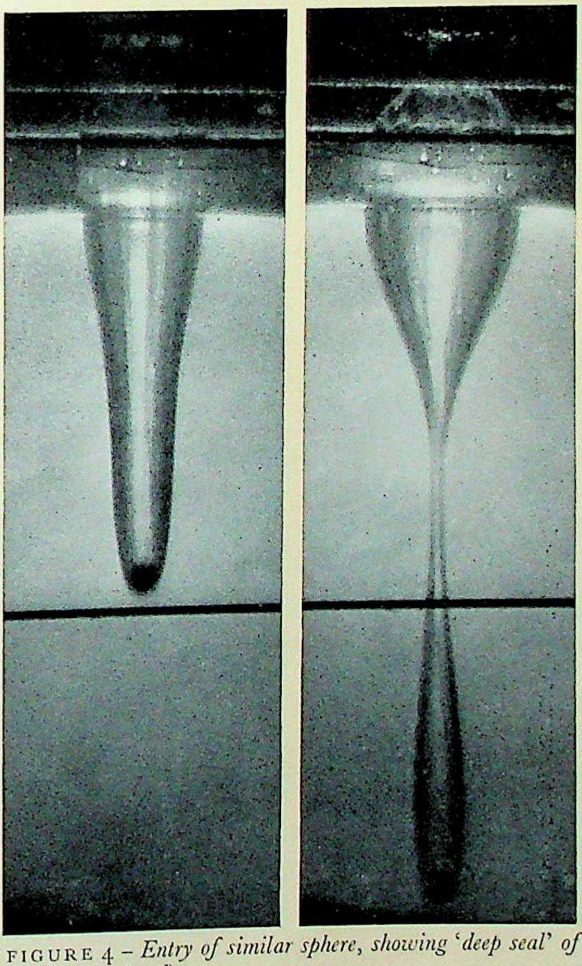

FIGURE 4 – *Entry of similar sphere, showing 'deep seal' of cavity. (Reduced)*

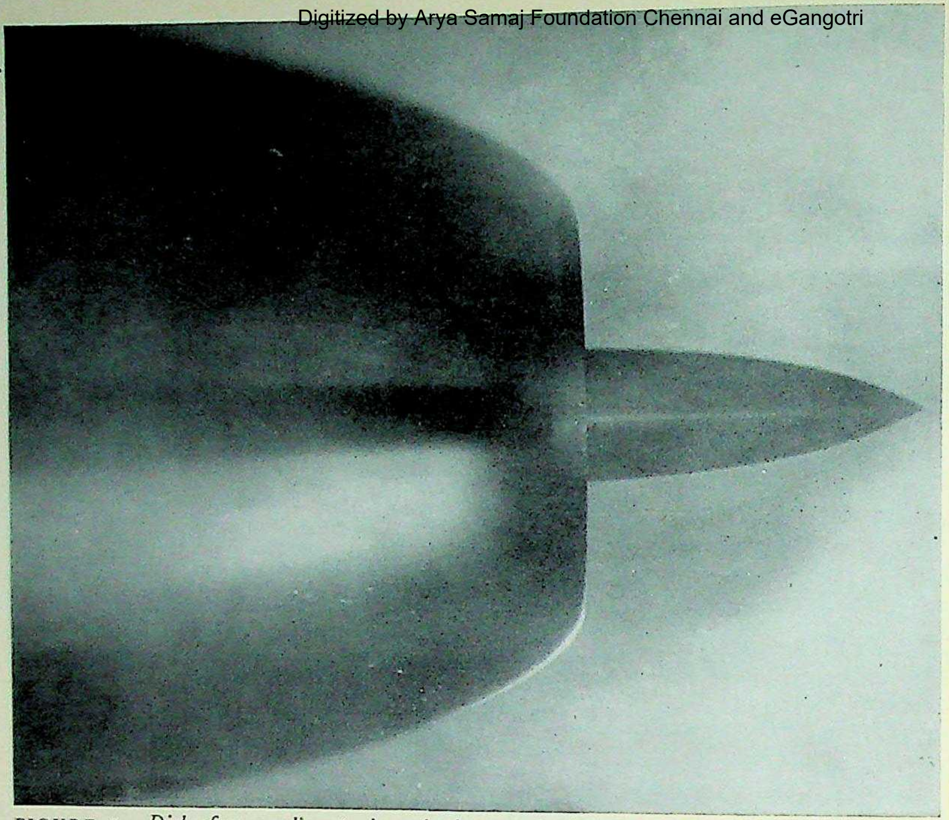

FIGURE 5 – *Disk of 10 cm diameter in cavitation tunnel with water flowing at 6 m/sec.* (× 0·5)

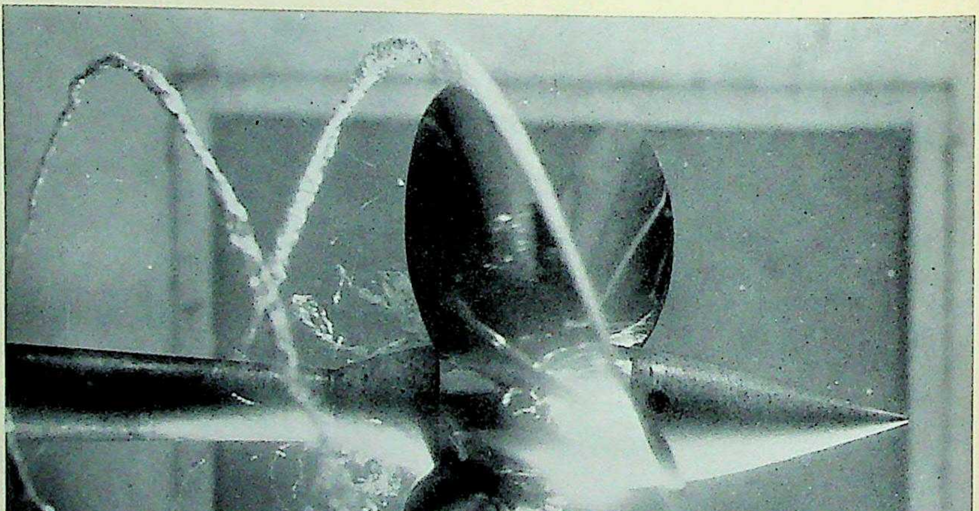

FIGURE 6 – *Propeller in cavitation tunnel.* (*Gawn*) (× 0·25)

On a less sharply curved body—say in the shape of a fish—when the speed is raised at the 'shoulders,' or places of greatest curvature, cavitation first appears as a chain of little vaporous cavities which tend to collapse, giving an appearance of soapsuds. If vortex formation is going on at any point on the body before cavitation, the cores of vortices seem to act as nuclei for the vapour. As the speed increases, so do the rate of vapour formation and the size of the bubbles, until the bubbles combine, forming a sock which envelops the tips of moving propellers or the whole rear portion of the stationary obstacle.

Figure 6 is a photograph of a propeller in a cavitation tunnel in which, owing to the rotation of the blades, the cavities are left behind in the form of helices. The pressure of the atmosphere over the water affects the nature of these cavities, just as it affects those formed on impact. Naturally, the presence of dissolved air in the water will encourage cavities by forming nuclei, so that, for standardization, all propeller tunnels have the air removed by continual pumping. For the same reason, leakages of air into the water through the joints of the tunnel must be sedulously avoided.

Why, then, is this type of cavitation so closely studied by applied scientists today? Firstly, as Parsons showed, erosion of the metal of the body, especially of the tips of propellers, rapidly spoils the surface and eventually tears it into holes. The surface of the solid becomes pitted by the impact of the water as the cavities collapse. The rate of collapse is such that, as Rayleigh showed, pressures of several thousand atmospheres may be set up inside the bubbles. The erosion is due to a rapid series of hammer-blows and may, in fact, be imitated by playing a high-speed jet of water on the spokes of a rapidly revolving wheel. Secondly, even if this erosion should be minimized as the result of the metallurgical studies of propeller materials now going on, the hydrodynamic resistance of a body having an attached cavity is much reduced. Thus the sphere of figure 3 has a resistance coefficient, at a speed of entry of 9 m/sec, of 0·28 as against 0·40 for a fully submerged sphere. This might be thought an advantage until one reflects that the designer relies on this resistance to give the propeller-thrust which drives the ship. In fact, the cavitating tips lose their bite on the fluid, just as do the tips of an aircraft propeller in the rarefied air of the stratosphere. Thirdly, the collapse of the cavities is a noisy process (the 'singing propeller').

Faced with these undesirable concomitants of high speed, scientists are trying by experiments in cavitation tunnels to find the conditions under which the onset of this phenomenon may be deferred to as high a speed as possible. This is sometimes done on the actual propeller; photographs such as that of figure 6 are taken, and the torque and thrust on the propeller are measured at the same time. The writer, however, feels that more can be learnt by observing stationary bodies of different shape in the tunnel, although this means that the running speed of the tunnel must be higher to induce the effect than if a rapidly rotating propeller is being studied.

Meanwhile, one remedy is obvious, viz. to round off the edges of the propeller blades, but this the designer is loath to accept, for it reduces the efficiency of the propeller. Some such compromise may have, however, to be adopted.

There is a third way in which cavities may be set up. We have referred above to cavitation as induced by excessive accelerations in the fluid. These can occur not only in straightforward flow but in the high peak accelerations of the alternating flow in the neighbourhood of submerged ultrasonic generators. There is nothing here specific to the high frequency, but since the acceleration in S.H.M. is proportional to the square of the frequency, the requisite peak acceleration is the more readily reached if the frequency is high. Many of the reported effects of ultrasonic agitation in liquids, such as degassing, the killing of bacterial cultures, and the breaking down of high-polymer molecules, are ascribed to the forces set up therein when the cavities are formed and subsequently collapse on to the surface of the ultrasonic source.

Owing to the difference in acoustic impedance between air (or a vacuum) and water or solid materials, this onset of cavitation limits the efficiency of a high-power ultrasonic signal generator. In this sphere, too, research is being carried out to extend the limit to higher outputs.

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Molecular compounds

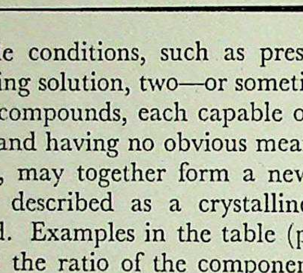
H. M. POWELL

It is not uncommon in chemistry to find that new methods of investigation lead to the discovery of quite unexpected properties in substances so well known that it would seem that there was little further to be discovered about them. Thus, recent research has shown that some familiar compounds can form molecular compounds in which two substances are firmly bound together because, in the crystalline structure, one substance encloses a system of spaces into which the other can fit but from which it cannot escape again.

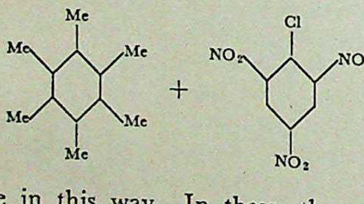
In suitable conditions, such as presence in the same cooling solution, two—or sometimes more—chemical compounds, each capable of a separate existence and having no obvious means of chemical union, may together form a new crystalline substance described as a crystalline molecular compound. Examples in the table (p. 157) illustrate how the ratio of the component molecules may be constant or variable, simple or complex.

The table gives a few examples only, and the arrangement into three groups is merely a convenience for illustrating the manner in which, for the selected examples, the molecular form and ratio of the components may vary.

In type I, considerable variations of both components may be made without affecting the possibility of compound formation or the general formula. Thus the molecular pairs:



and



combine in this way. In these, the molecular ratio 1 : 1 does not require an ordinary chemical linkage between the pairs of molecules, since it may arise from regularity of packing; according to crystal-structure analysis of one such compound no pair comprised of an atom from A and one from B has the short interatomic distance required for a covalent bond. It is reasonable in this group to attribute the compound formation to some pronounced form of residual attraction, possibly involving particular parts of the molecules. This attraction will be present provided certain features of the molecules are preserved—here the three nitro groups or their analogues in one, and the aromatic ring system of the other.

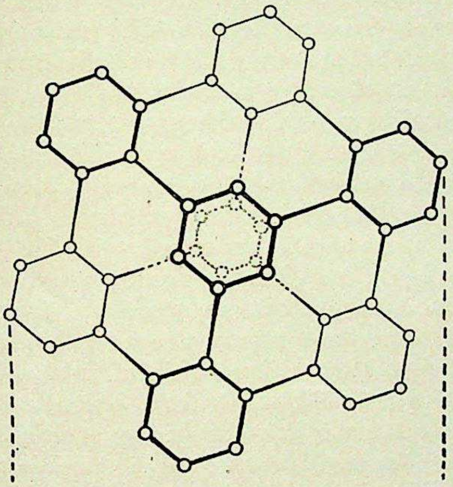
In type II, one component remains constant and the molecules of the second bear some structural resemblance to each other. Although they may differ also in other ways, the chief difference is often one of molecular length, the various molecules being related to each other in the same way as members of a homologous series. In these crystals, a framework of one component leaves a set of parallel, roughly cylindrical, channels in which rod-like molecules of the second component are arranged lengthwise.

Three factors are of importance in relation to this arrangement: (1) As a rule the framework structure is not that adopted by the framework-forming component when it crystallizes alone, so that examination of the structures of the pure components does not provide in any direct manner an indication of substances which are likely to form such compounds. (2) The framework and dimensions of the channels, being subject only to minor variations, restrict the second component to those substances which have molecules of a size and shape which will fit into the available space. Thus the molecules of the normal paraffins fit into channels formed by urea molecules, but the entry into similar combination of the branched isomers is prevented by their excrescences, which cannot be accommodated in the channels. (3) The composition of the compound formed depends on the length of the rod-like molecule which has to be fitted into the cylindrical space. In general, the number of molecules in the channels will be inversely proportional to their lengths, as is found in the dinitrodiphenyl compounds, and it is not necessary that there should be a simple ratio between the number of molecules in the channels and the number of the molecules required to form the framework. This is illustrated by the urea-hydrocarbon series.

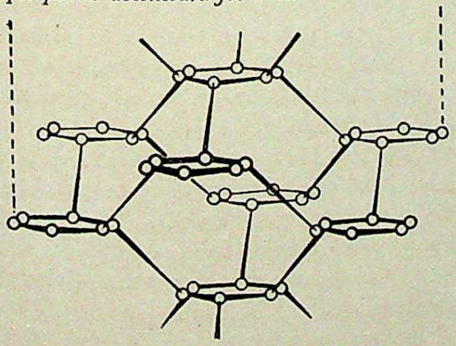
In compounds of type III, one component

remains constant and the possible variations of the second component depend not on chemical similarities but on molecular size. Members of homologous series do not replace each other, but similarly sized molecules may do so. Thus, the series of quinol compounds given in the table has for the second component such chemically different substances as hydrogen sulphide, sulphur dioxide, methanol, acetylene, carbon dioxide, formic acid, and argon. However, similar compounds are not formed by resorcinol, an isomer of quinol, and hydrogen sulphide cannot be replaced by water, methanol by ethanol, or argon by helium.

FIGURE 1 – *Manner of hydrogen bonding of quinol molecules.*



(a) *In plan. Each regular hexagon denotes six hydrogen bonds between oxygen atoms. Hexagons at different levels are represented by different line thickness. The tapered lines, representing the O—O axis of a quinol molecule, show the method of linking to form an infinite three-dimensional cagework. Each taper points downward from the observer.*



(b) *Perspective drawing corresponding to the above. The hexagons denote the hydrogen bonds; the longer lines connecting different hexagons denote the O—O axis of the quinol molecule. The complete structure as found in the molecular compounds consists of the cagework shown, together with a second identical interpenetrating cagework, which is displaced vertically half-way between the top and bottom hexagons.*

Structural investigations show that in these compounds quinol forms a structure which encloses molecules of the second component in cavities of limited size. In such compounds, which have been called clathrate compounds, each molecule of the second component is enclosed in a separate molecular cage from which it cannot escape. The manner of enclosure is illustrated in figures 2 and 3.

The following points of behaviour in the series emerge from a study of the structure:

(1) The tenacity with which the normally volatile constituent is held in molecular association with quinol is not explained by the mutual attraction of the components. This may be illustrated by the argon compound. The van der Waals interaction of argon with resorcinol does not cause molecular compound formation, and no very different interaction is to be expected when the isomeric quinol replaces resorcinol. Yet the crystalline argon compound shows a negligible pressure of argon and may be preserved unchanged for prolonged periods. This is attributed to the imprisoning action of the molecular cages in which the argon atoms are enclosed. As may be seen in figure 3, each atom is closely shut in between the surrounding quinol molecules, which are themselves held together by comparatively strong hydrogen bonds. To escape from its enclosure, the atom must pass through an escape

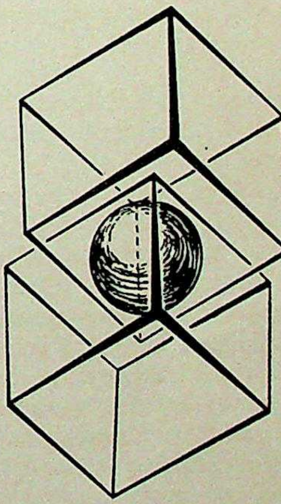
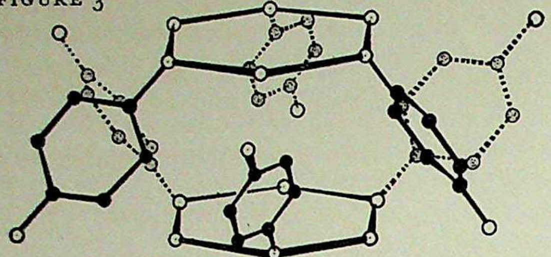
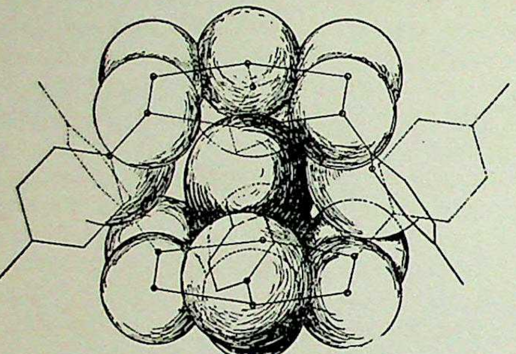


FIGURE 2 – *Schematic representation of enclosure. The enclosed molecule is represented by a sphere imprisoned by two interpenetrating cage structures. Each edge of the cage may be looked upon as containing one quinol molecule, and the real structure consists not of the limited cagework shown, but of the indefinitely extended pattern obtained by the prolongation of the edges to form an array of similar cages.*

FIGURE 3



(a) *The positions of the six quinol molecules that form the immediate surroundings of an argon atom are shown in a perspective drawing. This is deceptive because the centres of the atoms are shown, and the space occupied by the atoms cannot be shown at the same time.*



(b) *The spaces occupied by the atoms are indicated in a drawing on the same scale as that above. A few only of the atoms surrounding the central argon atom are shown. They are distinguished from those which have been omitted by small circles drawn around their centres. Broken lines are used to indicate that a part of the structure so represented lies behind some portion drawn with full lines.*

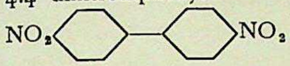
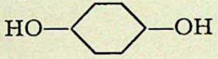
hole whose centre is much closer to the surrounding cagework atoms than the equilibrium van der Waals distances between unlinked atoms. In approaching such a position, the atom will be subjected to the forces of mutual repulsion that develop when any two atoms are sufficiently close. These forces, evident in the comparative incompressibility of molecular liquids and solids, increase greatly in their intensity as the interatomic distance diminishes below the equilibrium value, and, the cage being held together by strong forces, the enclosed atom will be forced back. There will always be some attraction due to van der Waals or other forces between the enclosed and enclosing components of such a molecular compound, and it may be of great importance in bringing the molecules into the correct positions for enclosure when the crystal is formed, but once the atom or molecule is enclosed it cannot escape merely by overcoming this attraction.

(2) The volatile component will be set free in processes which destroy the cage structure. Thus, argon is set free when the quinol-argon compound is heated to temperatures at which quinol molecules break their hydrogen bonds and volatilize. The gas is also liberated by dissolution of the compound in any solvent for quinol.

(3) Compound formation is restricted to particular pairs of molecules by geometrical rather than by chemical characteristics. Thus, the arrangement shown in figure 1 has six —OH groups of six different quinol molecules in the form of a hexagon, with the O—C bonds pointing alternately above and below the hexagons in such a manner that these bonds are at approximately the tetrahedral angle to the hydrogen bonds, as is commonly the case. If the —OH groups remote from these six are made geometrically equivalent to the first set, they in their turn form part of other hydrogen-bonded hexagons, and the result is the extended giant molecule which, with its identical interpenetrant twin, forms the enclosing structure of the molecular compounds. Substitution of the isomeric resorcinol, with the —OH groups in different relative positions in the molecule, is a drastic change geometrically incompatible with these requirements. This molecule therefore cannot replace quinol, although it is conceivable that it might form compounds of a similar character on a different geometrical plan.

Since the cavities are of predetermined form, apart from the minor variations, the only molecules capable of enclosure are those which have a size and shape that can fit into the available space, and which at the same time are large enough not to escape through the holes. With quinol, the methanol molecule is enclosed, but the ethanol molecule is too large and the water molecule too small. Argon is enclosed, but the helium atom, well known for its ability to penetrate small holes, does not give a similar compound.

(4) There is a limiting composition, determined by the ratio of the number of cage-forming molecules to the number of cavities. The second component may be present in quantity less than the permitted maximum because some of the cavities are unoccupied. It is found in the case of the quinol β-type compounds that, when the compound is obtained by simple crystallization from the second component, e.g. methanol or methyl cyanide used as solvent, almost all the cavities are occupied, and the ideal formula 3 quinol/M is attained. When it is necessary to use an indifferent solvent to get the two components together,

	Component A	*Component B*	*Composition of molecular compound*
I	Aromatic polynitro compounds such as *s*-trinitrobenzene (1)	Aromatic hydrocarbons and their derivatives, e.g. naphthalene or aniline	Frequently A.B., but other simple ratios are known.
II	4:4′ dinitrodiphenyl (2)  	4:4′ substituted diphenyls	$A_n.B$ *n* increases as length of molecule B is increased. For B = 4:4′-diacetoxydiphenyl, $n = 5$; for others $n = 4, 3\frac{1}{2}, 3$ according to molecular length.
	Deoxycholic acid .. (3)	Fatty acids, normal paraffins, and some other substances	$A_n.B$. $n = 1, 3, 4, 6$, or 8, increasing as length of fatty acid molecule increases.
	Urea .. .. .. (4)	Normal paraffins, carboxylic acids, alcohols, esters, etc.	$A_n.B$. *n* in general not integral and having values from 4 upwards, increasing with increase in length of molecule B.
III	Quinol (5)  	MeOH, MeCN	$A_3.B$
	Quinol	H_2S, SO_2, HCl, HBr, HCN, CO_2, C_2H_2, A, Kr, Xe	Approximating to A_3B, but with less B than formula requires and with variable proportion of B.
	Complex structure of composition $Ni(CN)_2.NH_3$ (6)	Benzene, thiophene, and a few similar molecules, but not the homologues	A.B

a considerable proportion of spaces may be left vacant. This is noticed for compounds such as those containing hydrogen sulphide, sulphur dioxide, and hydrogen bromide. Since the difficulty of getting a molecule into an already formed empty cavity is the same as that of getting it out of an occupied one, these vacant spaces, once formed, are preserved, and the frequency of their occurrence must depend on factors (such as concentration of the dissolved volatile component) which affect the chance of its molecules being in the position for enclosure at the instant when the cage is formed. Some of the compounds are therefore formed by crystallization of solutions of quinol in which the concentration of the dissolved gas is raised by pressure.

Knowledge of the nature of molecular compounds helps in the solution of some problems, and various possibilities of using it suggest themselves.

Sometimes a molecular compound has been mistaken for one of its components. Thus, the substance formerly called β-quinol, a supposedly polymorphic form of quinol obtained by crystallization from methanol, proves to be the methanol compound belonging to the clathrate series already mentioned. However, the hidden character of the methanol compound is such that this substance has survived a number of investigations of its properties up to the most recent times without detection of the masquerade. Unfamiliar molecular ratios, and a small proportion of one component, may add to the difficulty of detection. Elementary analysis could fail in particular cases when the components have similar compositions, and since the molecular compound decomposes on solution its reactions may appear to be entirely those of the component which it is thought to be. In particular, if the other constituent is the same as the solvent used the deception is complete.

More frequently, however, a substance, whose constitution does not seem to be otherwise in doubt, may give unexpected analytical figures which are due to the solvent combining in this way. Once the possibility is suspected the solution of the problem is not difficult.

There are possibilities for the use of such compounds in processes of purification, separation, identification, and quantitative estimation. Attempted purification of a substance by some methods becomes difficult owing to the continued presence of those impurities which have similar solubility, volatility, or other properties, and at this important stage a means of separation dependent on a different factor may be applied. Molecular size and shape may be so different that the separation may be made as complete as one based, at an earlier stage, on some profound chemical difference. The case of the urea-hydrocarbon compounds already mentioned illustrates different behaviour of straight-chain and branched isomers. In crystals containing long molecules in channels, the different members of a straight-chain series may not be separable, but in the clathrate types where closed cavities of fixed dimensions are occupied there is a highly selective action. This is illustrated by the formation by quinol of this kind of compound with methanol alone of the alcohols, since methanol is the only one with a molecule of a size to fit the available space.

In a somewhat similar manner the nickel cyanide/ammonia complex forms compounds with benzene and a few other substances, such as thiophene, furane, pyrrole, aniline, and phenol. The cage formation of the nickel cyanide/ammonia complex is perhaps not so complete as that of the quinol compounds, but it is extremely difficult to remove the benzene from the compound, and the action in combining with benzene has for years been regarded as so specific as to afford a means of quantitative gas analysis. Benzene may thus be separated from non-aromatic hydrocarbons and from its own homologues.

The reasons for the formation of these compounds, and the circumstances in which they are likely to occur, cannot be considered in this article, but some indication of their possible significance in other fields may be given. The association of two substances without the necessity of chemical combination in the ordinary senses may be common in nature. Loose compounds of the kind discussed may be of importance in biological systems. There is a clear illustration of specificity associated with the fitting together of two molecular components in some of these structures, which may serve as models for the much more complex molecular arrangements in living matter.

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Book reviews

CHEMOTHERAPEUTICS

Chemical Constitution and Biological Activity, *by W. A. Sexton, with a Foreword by A. R. Todd. Pp.* 434, *with* 42 *figures and* 58 *tables. E. and F. N. Spon Limited, London.* 1949. 55*s. net.*

The rapid increase in our knowledge of the chemistry of biological materials now permits a more fundamental approach to be made to the problems of chemotherapy. In this volume Dr Sexton brings together a wealth of information concerning the biological activity of chemical substances, and discusses in detail the relation between chemical constitution and biological response. The book is divided into two parts. The first five chapters contain synopses of the fundamental scientific principles involved, including a survey of proteins, enzymes, macromolecules of biological importance, the physical chemistry of bacterial growth, and so on. The remaining sixteen chapters give detailed accounts of the action of the many substances which have been used in chemotherapy, and chapters on insecticides and plant-growth regulators are also included. The story is a fascinating one for the general reader, who will be amazed at the amount of careful work which has already been done in this field, and the book with its tables, summaries, and references will be indispensable to the research worker. Many spectacular results have been achieved, including, for instance, the sulphonamide drugs, penicillin, Paludrine, and Antrycide, and within certain groups considerable correlation between structure and activity has been achieved. But the main impression given by Dr Sexton's balanced and comprehensive survey of these vitally important topics is of the need for yet more investigations, both biological and chemical, before a full understanding will be possible of the mechanisms by which chemotherapeutic materials exert their effects.

E. L. HIRST

ORGANIC CHLORINE COMPOUNDS

The Preparation, Properties, Chemical Behaviour, and Identification of Organic Chlorine Compounds. Tables of Data on Selected Compounds of Order III. *By E. H. Huntress. Pp. xxv + 1443. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1948. 165*s. net.*

This volume deals in detail with some thirteen hundred compounds containing carbon and chlorine; carbon, oxygen, and chlorine; carbon, hydrogen, and chlorine; or carbon, hydrogen, oxygen, and chlorine. It differs notably from the earlier volume, published jointly with the late Professor S. P. Mulliken, in that, although the general method of classifying compounds is retained, the treatment is in no sense restricted to problems of identification but includes an account of preparative methods, physical properties, and general chemical behaviour. Over twenty thousand literature references are given, and, since a fair number of the compounds dealt with are relatively new, the book will in these cases serve as a supplement to Beilstein. References to patents are also given, and in this and other respects the work will be of special value to industrial users. The first chapter is devoted to a detailed explanation of the method of classification used, and formulae and name indexes, as well as an index based on chemical types, are provided. In a reference book of this sort much depends on accuracy, completeness, and systematic presentation. There is every indication that Professor Huntress has had these criteria constantly before him in bringing to so satisfactory a conclusion a formidable but most valuable task.

H. J. EMELÉUS

ORGANIC REACTIONS

Organic Reactions, Vol. IV. *Edited by Roger Adams, W. E. Bachmann, A. H. Blatt, L. F. Fieser, J. R. Johnson, and H. R. Snyder. Pp.* 428. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1948. 36*s. net.*

This, the latest issue of a well-known series of handbooks, proceeds on the lines laid down by its forerunners. The account of the Diels-Alder reaction, with its numerous variations, occupies over 170 pages, presenting the most extensive summary which has so far appeared. The discussion of this reaction refers to its mechanism, reversibility, stereochemical selectivity, side reactions, limitations, and abnormalities, including an interesting loss of sulphur from dinaphthylenethiophen. The light which this reaction has thrown upon the mechanism of polymerization is emphasized.

The preparation of amines from ammonia and an aldehyde or ketone with a reducing agent, including Raney nickel, is also described. The possible intermediate formation of a Schiff's base in the reaction as catalysed by nickel or metallic oxides is discussed, and also the formation of by-products, e.g. pyridine bases. The chapters on the analogues of benzoin contain a useful theoretical discussion on the formation of acyloins from esters or acid chlorides and sodium. In discussing the use of hydrazine for the reduction of carbonyl groups the Wolff and the Kishner reactions are distinguished, and are critically compared with the Clemmensen reaction. The catalytic reduction of acid chlorides and the formation of quinones by oxidation also receive considerable attention. The tables of information regarding compounds prepared by, or undergoing, these reactions occupy 40 per cent. of the book.

FREDERICK CHALLENGER

SYNTHETIC RUBBER

Modern Synthetic Rubber, *by H. Barron. 3rd edition. Pp. xx* + 636. *Chapman and Hall Limited, London.* 1949. 45*s. net.*

Nobody could deny that this is an attractive book, but it is impossible to decide whether the author intended it to be a semi-popular exposition or a serious textbook. In fact, it has fallen between the two extremes. The book is based on what the author describes as a 'simple system,' but the system is actually complex and unnecessary. To describe an artificial rubber as a synthetic rubber is much nearer the truth than to describe such hard plastics as polyvinyl chloride or polythene as 'synthetic elastics.' It is doubtful if any purpose is served by including plastics which can be made to a certain extent rubbery by plasticization in a book on synthetic rubbers. In the opinion of the reviewer a greater effort on the part of the author to master the contents of the C.I.O.S. and B.I.O.S. reports before attempting to summarize them would have been time more profitably spent. For example, under 'latex stripping' the author appears to have missed the barometer principle in the design of this important piece of equipment. The third edition is without question a great improvement on the earlier editions, but the fourth edition should be expedited to eliminate the still remaining errors, such as the statement that polythene is unaffected by ultra-violet light, that rubber is the *trans* isomer of polyisoprene, and so forth.

W. J. S. NAUNTON

CARBOHYDRATE CHEMISTRY

An Introduction to the Chemistry of Carbohydrates, *by John Honeyman. Pp.* 143, *with line diagrams. Oxford University Press, London.* 1948. 15*s. net.*

Dr Honeyman has been successful in producing a readable textbook on carbohydrate chemistry. The subject has been developed in a logical manner; the treatment of the chemistry of the monosaccharides is good, and there is a useful section on cellulose derivatives in Chapter XI. One thought Chapter IX to be too short to be of real value, however, and that the important synthetic work of Burkhardt Helferich might have found a place in Chapter X. The formulation of inulin (p. 133) seems unfortunate, since the β-linkage is the most probable for this polysaccharide, and the statement that alginic acid is extracted from seaweed by sodium hydroxide should be corrected.

It must also be stated that the system used for references breaks down occasionally, for a student seeking the original papers on end-group assay under Haworth (1928) would experience difficulty in finding them, since the work was not carried out until 1932; in any case it is doubtful if many degree students will afford the time to search the abstracts as advised in the preface. Apart from such minor blemishes, the book must be warmly commended.

E. G. V. PERCIVAL

ORGANIC SYNTHESES

Organic Syntheses (Volume 28). *Editor-in-Chief, H. R. Snyder. Pp.* 121, *with several line illustrations. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 15*s. net.*

This volume of 'Organic Syntheses' contains detailed instructions for the preparation of a number of organic compounds. The instructions are considerably more precise than those which are usually given in original publications, where the preparations are often so condensed that the non-specialist has difficulty in repeating them. The unsatisfactory descriptions of many preparations in chemical journals are, however, not always due to brevity; yields are frequently not recorded, temperature and duration of reaction are masked by such phrases as 'warmed for a few minutes,' or a reaction is stated to be carried out 'in the usual manner.' Experience has shown that the reactions described in 'Organic Syntheses' will proceed as described, and give the final product in the yield and of the purity claimed. There are many additional notes, references to original literature, and mention of alternative methods of preparation. A list of the thirty-seven preparations is given below:

2-Acetothienone (2-acetylthiophen), 2-acetylfluorene, 9-acetylphenanthrene, 2-allylcyclohexanone, *o*-aminobenzaldehyde, *p*-aminophenyl disulphide, benzoyl disulphide, 9-bromophenanthrene, 4-bromo-*o*-xylene, 3-carbethoxycoumarin, *p*-chloroacetylacetanilide, *m*-chlorophenylmethylcarbinol, *m*-chlorostyrene, 9-cyanophenanthrene, *trans*-1:2-cyclohexandiol, 4:7-dichloroquinoline, 2:5-dihydroxyacetophenone, di-*iso*valerylmethane, 3:4-dimethylaniline, 2:4-dimethylquinoline, 1:4-dinitronaphthalene, diphenylacetonitrile, ethyl azodicarboxylate, ethyl ethoxymethylenemalonate, fluorenone-2-carboxylic acid, hexamethylene chlorohydrin, hydroquinone diacetate, 2-hydroxycinchoninic acid, *dl-iso*propylideneglycerol, methyl-4-keto-7-methyloctanoate, 4-nitro-1-naphthylamine, *p*-nitrophenyl sulphide, phenanthrene-9-aldehyde, 1-phenyl-3-amino-5-pyrazolone, α-phenylthiourea, 2:4:7-trinitrofluorenone, vinyl chloroacetate.

The subject index covers the contents of volumes 20–28.

W. BAKER

GENII OF THE CRUCIBLE

Crucibles: the Story of Chemistry from Ancient Alchemy to Nuclear Fission, *by Bernard Jaffe. Second English edition. Pp. xiv + 480. Hutchinson's Scientific and Technical Publications, London.* 1949. 18*s. net.*

The great advances in chemistry that have occurred since the first English edition of this book was published in 1931 have led to a drastic revision of the original last chapter and to the inclusion of three new chapters dealing with 'Ernest Orlando Lawrence,' 'The men who harnessed nuclear fission,' and 'Nuclear energy tomorrow.' In the complexities of sub-atomic chemistry, teamwork has played so great a part that in his closing chapters the author has had to abandon his device of dramatizing a specific figure as typical of a particular scientific era. The new part of the book paints a vivid picture of the marvels of the sub-atomic world, and of the unbounded energy and ingenuity of man in a work that may lead to his own destruction if he continues to develop cleverness at the expense of morality. Starting with alchemy—the treatment of which is superficial—here is a story unwinding at an increasing tempo and told with great zest. The last part of the book is easily the best. It gives a very readable account of the dominating part played in the more recent stages of sub-atomic chemistry by American physical scientists endowed with prodigious experimental resources. Although the second edition of this lively and human treatment contains some regrettable inaccuracies, it depicts the march of chemistry with a glowing enthusiasm worthy of the title.

JOHN READ

THE SERVICE OF SCIENCE

Science, Servant of Man. A Layman's Primer for the Age of Science, *by I. Bernard Cohen. Sigma Press, London.* 1949. 15*s. net.*

This is a book of some importance, written for the layman but affording food for thought to the scientist. Its purpose is to study the conditions under which scientific discoveries of practical value are made, and this intricate problem is handled clearly and with good sense. The various types of scientific discovery are examined, and it is clearly shown that no single description can cover all or even a majority. Some are happy accidents exploited by a curious and receptive mind, others are by-products of researches conducted for quite different ends, others again are the results of planned researches, others of the utilization of principles discovered many years before, at a time when no use for them could be found. A large part of the book consists of exemplary description of various researches, such as those that led to penicillin, synthetic rubber and nylon, hybrid corn, and the like: these seem to the reviewer to be well done and free from error. In surveying the method by which the greatest quantum of usefulness can be obtained from science, Mr Cohen comes down firmly against the enthusiasts for planning, quoting Dr Oliver E. Buckley, who says: 'All successful industrial directors have learned by experience that one thing a "director of research" must never do is to direct research. . . .'

F. SHERWOOD TAYLOR

FARADAY AND INDUCTION

Faraday's Discovery of Electro-magnetic Induction, *by Thomas Martin. Pp. 160, with half-tone and line illustrations. Edward Arnold and Co., London.* 1949. 9*s. net.*

Mr Martin is already well known as the patient and devoted editor of Faraday's diary, and little need therefore be said about the value of his latest book, which describes Faraday's work leading to the discovery of electromagnetic induction in all its fascinating detail, with facsimile reproductions of more than fifty of Faraday's freehand sketches.

Mr Martin emphasizes the importance of Faraday's earlier experiments in this field in 1821, and his close study of all that was done by others from 1821 to 1831—a period during which his attention was largely directed to other problems—until he then returned to continue his electrical researches without further interruption. Then came the rapid discoveries, from the ring experiment of 29th August to the production on 17th October of an induced current by the movement of a magnet in a coil of copper wire, and so on to the production of continuous currents by induction, of induced currents by means of the earth's magnetism, and of the 'magneto-electric spark.'

This excellent presentation of the sequence of Faraday's thoughts and experiments does much to reveal the mind and genius of that great master.

D. MCKIE

METAL PHYSICS

Progress in Metal Physics, *edited by Bruce Chalmers. Pp. 401. Butterworth's Scientific Publications, London.* 1949. 45*s. net.*

The purpose of this volume is explained by the editor as being 'to present authoritative reviews of the present state of knowledge in specialized aspects of the field that includes both physical metallurgy and metal physics.' There are seven reviews in this first series, and it is intended to keep the work up to date by publishing subsequent articles confined to more recent progress. As the articles in the present volume are the first of the series they also include the necessary historical background.

Metal physics is a relatively new subject, the importance of which is being increasingly recognized. To the knowledge of the structure of metals as shown by the microscope, and the vast body of data about their physical properties, have now been added the knowledge of atomic pattern, crystallite size and strain obtained by X-rays, and the information about structure on a very minute scale revealed by the electron microscope. We are in a much stronger position to attempt to explain the physical properties of metals in terms of their atomic arrangement.

It is no criticism of the authors of the articles to say that the volume gives a deep impression of bewildering complexity. There is an extraordinary contrast between the extreme simplicity of the perfect crystal of a pure metal, of whose nature the atomic physicists have given us a reasonably complete explanation, and the complexity of behaviour when the ideal symmetry is destroyed. When alloys and solid solutions are considered, the complexity is almost infinitely increased. We still await the genius who can order and arrange these facts, and give us a clue to the maze by unifying and simplifying theory. The study of the theory of alloys is the most satisfactory, or perhaps one should say the least unsatisfactory, in this respect. Here one does begin to see bits of the jigsaw puzzle falling into place; the knowledge of atomic arrangement allied to the quantum theory has for the first time put metal chemistry on a hopeful basis. In the sections on the theory of dislocations and crystal boundaries, and their effects on slip and creep, hardening and fracture, one is still groping in the dark. Advance depends upon a much deeper understanding of the number and arrangement of the dislocations, the units in terms of which we seek to define the departure from the perfect crystalline form, and by whose movements we seek to explain the flow of the metal. Until more is known about their physical nature, such mathematical theory as has been developed is really little more than a conventional fig-leaf to cover the utter nakedness of intuitive guesses. The technologist still has to wait patiently for the advance of pure science which one day will give him a lead. The section on the hardening response of steels is more technical than the other sections, as is natural in view of the complexity of the phenomena. In the section on diffusion it is possible to use well-developed mathematical techniques, though here again the understanding of the fundamental physical phenomena is very incomplete.

We must be grateful to the authors for the patience and skill with which they have addressed themselves to the task of summarizing the subject of metal physics in its present state. Its importance in industry is very great indeed, and we must encourage research so that Britain may be in the forefront of development. In this review the researcher can find a reference to all the significant work which has been carried out in recent years, scattered widely over many journals, and it will be of the very greatest assistance to him.

W. L. BRAGG

HISTORY OF SUGAR

The History of Sugar, *by Noel Deerr. Vol.* 1, 1949, *pp.* 258, *with* 20 *plates,* 6 *figures, and* 8 *maps in text; Vol.* 2, 1950, *pp.* 259–636, *with* 11 *plates and* 42 *figures in the text. Chapman and Hall Limited, London.* 50*s. and* 55*s. net.*

This is a thorough historical survey of the sugar industry in its many aspects, and new and valuable materials, and some delightful illustrations, have been brought to light by the author's painstaking researches in libraries, domestic histories, long-buried journals, and other little-known sources. Although he begins by introducing us to prehistoric man in quest of honey, and to the many sources of sugar in nature, his main theme in volume 1 is the production of sugar from cane. The treatment is both detailed and comprehensive, and the subject-matter is so arranged that one can immediately gain a clear and adequate impression of the historical development of the industry whether in China, the Mediterranean, or the French West Indies.

Fourteen chapters in all are devoted to the establishment and development of the industry in different regions of the world. And what good reading this makes, not only because of the author's evident though restrained delight in the scholarship which has gone to the making of this work, but because, in a sense, and in no small degree, sugar and history are synonymous. That this is so becomes still more evident in Volume 2, where although, as the author tells us, his intentions were otherwise, he has been impelled to deal at length with the question of slavery. For, as the facts now before us show with convincing clarity, the rise of the sugar industry and the extension of industrial slavery were correlated to a remarkable extent, not only during the more recent centuries with which most people are somewhat familiar, but through the ages. To this harrowing but fascinating topic three chapters are devoted. For those who yearn for a glimpse of the old-time planter's life under tropic skies there is a most interesting account of 'The Plantation and the Planter.' Three chapters are devoted to the emancipation of slaves and consequential developments, and one to the 'blackbirding' traffic which persisted in some regions almost into our own times. Other chapters deal with the trade in sugar, sugar duties, refining, prices, etc., considerable space being devoted to the sugar beet industry and to minor sources of sugar; the more technical reader will find a condensed but valuable illustrated chapter on the effects of invention and research on the development of the industry. The author is to be congratulated on the sustained scholarship which characterizes this survey of one of the world's most vital crops, and the publishers on these handsome volumes.

C. W. WARDLAW

BRITISH SCIENTIFIC JOURNALS

A List of British Scientific Publications Reporting Original Work or Critical Reviews. *Pp.* 95. *Published for the Royal Society by the Cambridge University Press, London.* 1950. 2*s.* 6*d. net.*

At the Royal Society Scientific Information Conference held in 1946 many delegates felt that it would be of great value to have a list of the scientific journals published in the United Kingdom which include a substantial proportion of original work or critical reviews. This publication is the result of these recommendations. It does not claim to be comprehensive, but it lists about 220 journals, giving for each a short description of its contents and details of its frequency of publication, its current volume number, approximate size, whether summaries of papers are given, whether advertisements are accepted, where and how directions to authors can be obtained, its price, the editorial address, and the address of the publishing organization.

The book is well indexed, and any specific journal or the journals devoted to any one subject can be found without difficulty. It is to be hoped that the book will be kept in print and that in preparing future editions the list will be even more comprehensive.

Some books received

(*Note:* Mention of a book on this page does not preclude subsequent review.)

AGRICULTURE

Soils—Their Physics and Chemistry, *by A. W. Puri. Pp.* 550, *with several line diagrams. Reinhold Publishing Company, New York; Chapman and Hall Limited, London.* 1949. 56*s. net.*

ASTRONOMY

Cosmical Electro-Dynamics, *by H. Alfvén. Pp.* 237, *with various line diagrams. Oxford University Press, London.* 1950. 25*s. net.*

BIOLOGY

Biology, *by P. D. F. Murray. Pp.* 600, *with numerous line drawings and half-tones. Macmillan and Company Limited, London.* 1950. 25*s. net.*

The Biology of Melanomas. *Editor: Roy Waldo Miner; Consulting Editor: Myron Gordon. Pp.* 466, *with half-tone and line illustrations. New York Academy of Sciences.* 1948. $5 *net.*

Evolution, *by Chapman Pincher. Pp.* 199, *with various line diagrams. Herbert Jenkins Limited, London.* 1950. 7*s.* 6*d. net.*

BOTANY

Adaptation and Origin in the Plant World, *by Frederic E. Clements, Emmett V. Martin, and Frances L. Long. Pp.* 332, *with numerous half-tones and line diagrams. Chronica Botanica Company, Waltham, Mass., U.S.A.*

Water in the Physiology of Plants, *by A. S. Crafts, H. B. Currier, and C. R. Stocking. Pp.* 240, *with several line diagrams. Chronica Botanica Company, Waltham, Mass., U.S.A.; Wm. Dawson and Sons Limited, London.* 1949. $6 *net.*

CARTOGRAPHY

Aerial Mapping and Photogrammetry, *by Lyle G. Trorey. Pp.* 178, *with numerous half-tones and line diagrams. Cambridge University Press, London.* 1950. 25*s. net.*

CHEMISTRY

Advanced Chemical Calculations, *by S. J. Smith. Pp.* 454. *Macmillan and Company Limited, London.* 1950. 17*s. net.*

Advanced Organic Chemistry (*second edition*), *by G. E. Wheland. Pp.* 799. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 64*s. net.*

Boron Trifluoride and its Derivatives, *by Harold Simmons Booth and Donald Ray Martin. Pp.* 315, *with several line diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 40*s. net.*

The Chemical Elements and their Compounds, *by N. V. Sidgwick. Two volumes, pp.* 1703. *Oxford University Press, London.* 1950. 70*s. net.*

Organic Chemistry, *by Paul Karrer. Fourth English edition. Pp.* 983. *Elsevier Publishing Company Limited, Amsterdam; Cleaver-Hume Press, London.* 1950. 57*s.* 6*d. net.*

Organic Reactions, *Vol. V. Editor-in-Chief: Roger Adams. Pp.* 446. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 48*s. net.*

Solvents, *by R. H. Durrans. Pp.* 242. *Chapman and Hall Limited, London.* 1950. 21*s. net.*

Structural Carbohydrate Chemistry, *by E. G. V. Percival. Pp.* 246, *with several line diagrams. Frederick Muller Limited, London.* 1950. 25*s. net.*

ENGINEERING

Aerials for Centimetre Wave-Lengths, *by D. W. Fry and F. K. Goward. Pp.* 172, *with numerous line diagrams. Cambridge University Press, London.* 1950. 18*s. net.*

The Mathematical Theory of Communication, *by C. E. Shannon and W. Weaver. Pp.* 117. *University of Illinois Press, U.S.A.* 1949. $2.50 *net.*

GENERAL SCIENCE

The Growth of Scientific Ideas, *by W. P. D. Wightman. Pp.* 495, *with various half-tone and line illustrations. Oliver and Boyd Limited, Edinburgh.* 1950. 25*s. net.*

Science and Literary Criticism, *by Herbert Dingle. Pp.* 184. *Thomas Nelson and Sons Limited, Edinburgh.* 1949. 7*s.* 6*d. net.*

Science News No. 15, *edited by J. L. Crammer. Pp.* 192, *with half-tone and coloured illustrations. Penguin Books, London.* 1950. 1*s.* 6*d. net.*

INDUSTRY

Co-operative Industrial Research, *by Ronald S. Edwards. Pp.* 285. *Pitman and Sons Limited, London.* 1950. 20*s. net.*

Freeze-Drying—Drying by Sublimation, *by Earl W. Flosdorf. Pp.* 280, *with numerous half-tone and line illustrations. Reinhold Publishing Company, New York; Chapman and Hall Limited, London.* 1949. 40*s. net.*

MEDICINE

Human Ability, *by C. Spearman and Ll. Wynn Jones. Pp.* 198. *Macmillan and Company Limited, London.* 1950. 16*s. net.*

Recent Advances in the Physiology of Vision, *by Hamilton Hartridge. Pp.* 401, *with numerous line diagrams. J. and A. Churchill Limited, London.* 1950. 25*s. net.*

Temperature and Human Life, *by C.-E. A. Winslow and L. P. Herrington. Pp.* 272, *with various line diagrams. Oxford University Press, London.* 1949. 28*s. net.*

OCEANOGRAPHY

The Sea and its Mysteries, *by John S. Colman. Pp.* 285, *with various line drawings and half-tone illustrations. G. Bell and Sons Limited, London.* 1950. 12*s.* 6*d. net.*

PHYSICS

Counting Tubes, *by S. C. Curran and J. D. Craggs. Pp.* 238, *with several line diagrams. Butterworth's Scientific Publications Limited, London.* 1949. 35*s. net.*

Heat Transfer, *Vol.* 1, *by Max Jakob. Pp.* 758, *with several line diagrams. John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1949. 96*s. net.*

Phenomena, Atoms and Molecules, *by Irving Langmuir. Pp.* 436, *with several line diagrams. Philosophical Library, New York.* 1950. $10 *net.*

Physical Properties of Glass, *by J. E. Stanworth. Pp.* 224, *with line diagrams. Oxford University Press, London.* 1950. 21*s. net.*

The Physics of High Pressure, *by P. W. Bridgman. Pp.* 445, *with various half-tones and illustrations. G. Bell and Sons Limited, London.* 1950. 35*s. net.*

Radiative Transfer, *by S. Chandrasekhar. Pp.* 393, *with several line diagrams. Oxford University Press, London.* 1950. 35*s. net.*

ZOOLOGY

Practical Invertebrate Anatomy, *by W. S. Bullough. Pp.* 463, *with line diagrams. Macmillan and Company Limited, London.* 1950. 28*s. net.*

Traité de Zoologie, *Vol. XV.* Oiseaux. *Publié sous la direction de Pierre-P. Grassé. Pp.* 1164, *with many line drawings and half-tone illustrations. Masson et Cie., Paris.* 1950. 6000 *fr. net.*

ENDEAVOUR

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The conservation of museum objects

'A thing of beauty is a joy for ever: Its loveliness increases; it will never Pass into nothingness'. So sang the poet, truthfully in the sense he intended—but he was not the curator of a museum or art gallery. Interpreted with prosaic literalness, the assertion is diametrically opposed to the truth. Curators know only too well that tapestries fade or are devoured by moths; that paintings blacken; that illuminated manuscripts become brittle and fragile; and that palimpsests grow more and more illegible. In bygone days a melancholy resignation accepted such decay as inevitable, and did not do—indeed could not do—very much to prevent it.

Our own outlook is more hopeful. We realize that, whenever a collection of precious material is assembled in a museum or gallery, we have more considerations than those of historical research, documentation, public exhibitions, lectures, and so forth. There are also fundamental problems of a scientific and technical nature, which perhaps we have come to perceive through the success of science in solving similar problems in other fields. They concern the rational care of artistic treasure, anticipating wherever possible the causes of deterioration, devising methods of preventing it, and, where decay has already set in, restoring as nearly as may be to a condition acceptable and permanent. Stated thus, the problems clearly demand scientists for their solution, but it is not suggested that the duty of conservation can be adequately performed without reference to aesthetic criteria. On the contrary, such criteria must be continually to the fore; yet scientists have a perfectly defined task—namely to understand the 'mechanics' and to reason from them objectively.

This is not the occasion on which to enter into a discussion of the details of procedure, though the first term of reference must obviously be the structures of the objects to be conserved. Equally important is the influence of environment. In this connection it may be observed that experience of wartime repositories, with their attendant risks and sometimes unpredictable circumstances, proved conclusively the value of air-conditioning and the beneficial effects it has in prolonging the life of works of art. It cannot heal the lesions of the past, but it can do much to eliminate their causes, and thus to prevent their repetition.

In conservation, as in other matters, apparatus and all types of instrumentation are relatively useless without a well trained and competent staff, at every level. Nevertheless, until very recently, no world-wide body existed to establish professional standards and to encourage first-class quality, both in knowledge of materials and in technical ability. However, in the spring of this year (1950) the International Institute for the Conservation of Museum Objects was founded in London, the first attempt ever made to set up a corporation of fellows and associates—elected with great care—to deal with the problems of the well-being of all kinds of precious things. In the course of time, the new institute should take its place with the well-known professional organizations—e.g. of architects, engineers, physicists, chemists, and so forth—brought into being for the same general purpose, namely to raise the status of specialists, and to maintain, and indeed require, high standards.

A feature of this new venture is its international character. Obviously, it could scarcely be otherwise, having regard to the wide distribution of museum objects. Its founders, leading authorities on the theory and practice of conservation, have received many tokens of encouragement, but none, so far, to compare with the generosity of the Nuffield Foundation, which has promised the institute £500 every year for five years. From the United States (where the project was originally conceived), and from Belgium, financial aid has also been forthcoming, as well as from Britain in addition to the Nuffield gift. Like many another young enterprise, the new institute begins life with very modest means, and much of its work must necessarily be done as a labour of love. At the same time, it is much to be desired that its intentions should be widely known.

Nobody can view the present position with regard to the training and recruitment of conservators and restorers without grave misgivings. Admirable work is being done by individuals and institutions, academic and otherwise. Nevertheless, the need remains to combine just the right amount and type of scientific instruction and practical demonstration with due appreciation of the historical and aesthetic problems involved. At the Fogg Museum of Art at Harvard much has been, and is being, done. In London, at the Courtauld Institute, classes are in progress, and a refresher course for curators was tried this summer as an experiment, which it is hoped will justify itself and may become an annual event.

What, however, is required over and above all this, is a scheme of training applicable to every kind of museum object, and one which might in time acquire international recognition. Without the least desire, or indeed ability, to dictate, the new institute is empowered to grant diplomas when conditions permit, and it will try to inaugurate training schemes whenever and wherever it seems feasible to do so.

Lord Rutherford used to say that knowledge proceeds by the development of technique. True as this is, it needs the means of dissemination among all classes of interested persons. Until 1942, this was to a large extent achieved in these matters by the quarterly journal *Technical Studies in the Field of the Fine Arts*, published at Harvard under the editorship of G. L. Stout, who has been elected the first president of the new institute. The war brought about the demise of this distinguished periodical, since when the scientific and technical workers concerned have possessed no medium through which to make their investigations known. It is intended, as soon as possible, to remedy this misfortune by issuing a new publication under the aegis of the institute, and provisional arrangements are already in hand. Appearance of the journal at regular intervals will not be possible; the plan is for an issue to be produced whenever enough material of high quality has been collected to fill it. Meanwhile, a somewhat slighter bulletin is envisaged, to be circulated regularly and more frequently, to keep members informed of the institute's policy and activities.

Machinery for consultation and advice will be evolved gradually, so that co-operation with other bodies working in neighbouring fields of activity may be facilitated.

Such, in brief, is the skeleton of an organization to put the profession of conservation upon a more solid foundation than hitherto. Only time can show what the result will be, but the attempt itself is certainly not without significance. A broad generalization will perhaps illustrate this fact. In the important special case of the cleaning of pictures there is room, as is well known, for more than one school of thought and practice. Everybody who has had experience in this most difficult and delicate of tasks will agree that the skill of the restorer is a paramount consideration. Without it, knowledge of solvents, friction, paint-physics, molecular films, and all the rest may well be almost valueless. The same goes without saying with regard to integrity of purpose, and the will to co-operate with all others scientifically and technically qualified, in order that consultation may be effective and risks correspondingly reduced.

In the present state of knowledge, there can be no hard-and-fast rules, for the materials in question and their relationships to each other are too diverse, yet sensibility of observation combined with an objective approach should go far to overcome many of the obstacles encountered in the course of conservation and treatment.

The whole subject is, in fact, a study in very sensitive adjustment—to seek out the position of equilibrium between the use of empirical means, and that of rigorous scientific methods which must, by their very nature, act in a certain way and in no other.

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The physics of the deformation of metals

E. N. DA C. ANDRADE

The systematic study of metals is particularly difficult because many different structures are possible under identical conditions and the mechanical properties are largely determined by small local irregularities in the crystal lattice. Investigations carried out with metals in single crystal form have done much to reveal the essentials of the problems of deformation. As regards polycrystalline metals, one phenomenon which has lately come into prominence is that of creep, that is, the slow flow under high stress. Here certain general laws have been established and interesting prospects revealed, which are now engaging the attention of both academic and industrial men of science. This article describes some recent work.

One of the paradoxes which physics presents to the uninitiated is that the mechanical properties of the gaseous state, which cannot be ordinarily seen, or handled except in closed vessels, are so much easier to explain than those of the condensed—that is, solid or liquid—state, which is visible, palpable, and readily accessible to a variety of simple tests. The reason for this is, of course, that in the gaseous state the molecules are sparse, so that their complex behaviour when in close proximity comes into the question only at the collisions which, considering the whole history of a molecule, are relatively infrequent, and then concern only two, or at most three, molecules at a time. In the condensed state any molecule spends its whole life in the immediate neighbourhood of several others, and the prevailing forces, which involve the interaction of several electronic shells, offer a difficult problem which admits of approximate solutions only. From some points of view the crystalline solid is simpler than the liquid state, owing to the regularity of the structure: thus the theory of the specific heats of such solids is on a very sound basis, while the variation of the specific heats of liquids with temperature has so far received no satisfactory treatment. The fundamental difficulty of the solid state, however, is that in general it is not in thermodynamic equilibrium with its surroundings, whereas all ordinary liquids are so. This is particularly true of metals: a metal of a perfectly determined chemical species—that is, either a pure metal or one with definite proportions of other metals dissolved in it—under perfectly determined conditions of temperature and pressure, may have a variety of properties, especially mechanical properties; its behaviour will depend markedly upon its previous history. A mere reference to tempering, or to polish, will be sufficient to indicate what is meant. This variety is emphasized by the division of solid properties, particularly metallic properties, into two classes, structure-insensitive and structure-sensitive. Structure-insensitive properties are those which are comparatively slightly affected by small traces of impurity or by mechanical or thermal treatment—such properties are the specific heat, the overall crystal lattice constants, the density, the coefficient of thermal expansion, and the elastic constants. Structure-sensitive properties are the magnetic permeability and the elastic limit, the tensile strength, ductility, and flow properties—in general, all the mechanical properties of the metal. A striking example is afforded by certain manganese steels of determined composition, which, according to the structure produced by treatment, may be tough, ductile, and non-magnetic, or hard, brittle, and magnetic.

The great difficulties in the study of metals are caused, then, by the fact that very numerous structural differences are possible under like conditions, which means that most of the states in which a metal exists are metastable. In general, a metal in a given state remains indefinitely in that state at room temperature—but there are exceptions, such as the often-cited case of white (ordinary) tin slowly changing into grey tin at temperatures below 18° C, and the many alloys, e.g. various aluminium alloys, which harden if left to themselves at ordinary temperatures or, more rapidly, at a constant, higher temperature. This change, known as precipitation hardening, receives reference later.

If, then, we are going to seek an explanation of the ordinary mechanical properties of metals, we must consider their structure. In the first place, we will take pure metals. It is well known that ordinary metals consist of masses of small crystals, usually referred to as crystal grains, whose existence can be revealed by polishing[1] the metal and attacking its surface with a suitably chosen reagent which has a preferential action on the crystal boundaries (see figure 1) and frequently on different crystal faces—for individual chemical reagents usually differ in their rate of reaction on different faces of the same crystal. Remarkable cases of selective action were shown by Hausser and Scholz [2] with a sphere turned from a large single crystal of copper, whose preparation was a considerable technical feat. The oxidation that took place in air was confined to the cubic faces of the crystal structure. If the sphere was exposed to nitric acid in which mercury had been dissolved, the rhombic dodecahedron faces were covered with a mercury deposit, the individual faces being separated by bands of bright copper. Examples of the preferential attack on crystal faces of a more ordinary etching reagent are shown by figure 5, where the bright and the dark grains are attributable to this effect.

Another method of revealing the structure of metals by treating the surface in a way that shows selective action is by thermal etching, that is, by heating the metal until the surface layers have been removed by vaporization. This method has, for instance, been used by Chalmers and his collaborators for studying the structure of polycrystalline silver [3], and by Randall and myself for studying the local irregularities of single crystals of cadmium [4]. Chalmers and his collaborators have also studied the attack of gases on heated metals, and have shown that, for instance, oxygen is particularly effective as a revealer of structures. Figure 3 is of a silver surface attacked by oxygen at 900°, showing unstrained twins, while figure 4 is of silver thermally etched in air, showing grain boundaries as well as structure within the grain.

The nature of the intercrystalline boundary has long been a matter of dispute, one school holding that the grains are separated by a region some hundreds of atoms thick, in which the atoms are arranged in a disordered manner—the so-called 'amorphous cement'—and the other school maintaining that between two grains, in each of which a crystal order prevails, is a sheet, a few atoms thick only, the members of which, being under the influence of forces from both lattices, constitute a transitional layer. The latter picture is the one more generally accepted, and very recently Chalmers and his collaborators, applying consideration of free energy to the boundaries, have brought forward strong arguments in favour of it [5].

In a polycrystalline metal we have, then, both crystal grains and crystal boundaries to be considered when we come to seek an explanation of its properties. Further, we have to remember that, with a given metal, the average size of grain may vary within wide limits, according to the method of treatment, and that although the amount of impurity present may be very small—it is never absolutely zero—it may diffuse preferentially to the crystal boundaries, which comprehend so relatively few atoms that the proportion in this region may be appreciable. Again, as we shall see, mechanical deformation may greatly influence the structure and axial orientation of the crystal grains themselves. It should thus be clear that even a spectroscopically pure metal is a very complicated assembly. Its mechanical properties are, however, even more different from the predictions of simple theory than these first considerations of structure would suggest.

Let us turn to the simplest ideal crystal. If we consider two atoms only, they will be in equilibrium under an attractive force tending to bring them together, and a repulsive force which prevents them approaching indefinitely, the repulsive force decreasing with the distance much more rapidly than does the attractive force, with the result that there is equilibrium at E (figure 20), where the two are equal. In the complete lattice, the general picture of prevailing forces is much the same. We should therefore expect that if the lattice were strained, so that the atoms were separated, the resultant force would increase until it reached the maximum, as at M, and that then the metal would break. Until this stage is reached, the ideal lattice should behave elastically, recovering its original size and shape as the stress is removed. We should have, then, large, perfectly elastic deformations, not obeying Hooke's law. Further, we can estimate roughly the theoretical breaking stress of crystals. The only case where the interatomic forces are sufficiently ascertained to enable this to be done from lattice consideration is that of a simple ionic, rock-salt type. Here the result of calculation is that the crystal should fracture under tension at an extension of 14 per cent. and a stress of somewhere about 250 kilo wt/mm². A more general method of estimating the theoretical strength rests upon the energy of the fresh surface formed when a rod is broken under tension. The value of the surface energy is given by the surface tension, which in its turn is taken from the surface tension of the liquid, it being assumed that, since the interatomic distances are not much changed on melting, the surface energy of solid and liquid form will be about the same. This method applied to rock-salt gives roughly the same value as that obtained by considering the interatomic forces: applied to metals it gives brittle breaking stresses of the order of 3000 kilo wt/mm^2. Now the experimental breaking stress of rock-salt is about 0·5 kilo wt/mm^2, while for metals the elastic limit seldom reaches 50 kilo wt/mm^2 or the ultimate tensile strength twice this value. The strength of a metal, however it be defined, is even for the toughest steels scarcely a thirtieth of the value to be anticipated from theory for a perfect crystal. If we consider yield under shear we find a similar discrepancy. This very low strength is not the only way in which real metals behave very differently from theory. In general, the region of perfect elasticity is very small: the metal does not fracture in a brittle manner, but there is a large plastic yield, during which the metal toughens ('work-hardening') and, for higher temperatures and stresses, the metal under maintained stress does not retain the dimensions it takes up when first loaded, but slowly flows or 'creeps.' The fracture of metals is a particularly complicated subject, as can be seen from Orowan's recent study [6]. The brittle fracture of certain steels, to which public attention has been directed by the breaking of welded ships, is but one aspect of it, and here it is known that slight variations in the composition of the steel play a major part.

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[1] Recently the technique of polishing by electrolysis, in place of mechanical polishing, has been widely used. It has the great advantage of not breaking up the structure of the crystal surface, which suffers considerable local deformation in mechanical polishing [1].

At first, all these anomalies might seem attributable to the fact that the metal consists not of one crystal but of a great number of small crystals separated by the boundaries to which we have referred: these boundaries might reasonably be supposed to be a source of weakness. However, for the past few decades it has been possible to make metal specimens called single-crystal, in which the direction of the crystal axes, as tested by X-rays, is the same throughout. These single crystals can be made in various ways; for instance, by alternately straining and heating the specimen (method of Carpenter and Elam, used particularly for flat specimens); by systematic solidification of the melted metal, enclosed in a vessel, from one end (Tammann, Hausser and Scholz, and others); or by melting the metal locally by a travelling furnace (Andrade and Roscoe). These are only some examples: many other methods have been used. Single crystals are generally prepared in the form of wires or rods, which a superficial examination might easily take for polycrystalline metal; the fact that the crystal axes are everywhere directionally the same is easily demonstrated, however, by familiar X-ray methods. Figure 2 shows, for example, a Laue back-reflection picture of a gold single crystal, as contrasted with that of a polycrystalline gold specimen. The usual tests can, then, be carried out on specimens of the same size and shape, in which the metal is either polycrystalline or of single-crystal structure.

Strangely enough, the behaviour of metal in single-crystal form diverges from the anticipations of simple theory even more widely than does the behaviour of the ordinary polycrystalline metal. Usually, large plastic deformation begins to take place under stresses much lower than those required with polycrystalline metal: in the one or two cases where brittle fracture takes place (notably with bismuth under particular conditions) the tensile strength is very low, of the order of 1 kilo wt/mm^2. Deformation leads, in general, to very great work-hardening. What particularly strikes the eye, however, is that single-crystal wires, when extended, show a characteristic structure of bands, such as might be produced by slip, one relative to the other, of a series of parallel planes making a determined angle with the axis of the wire, and that, as the wire stretches, it takes on a flattened form, the normal cross-section becoming elliptical instead of circular. Figure 7 shows a single crystal of cadmium which has been extended by about 40 per cent. This stepped structure is not an effect of impurity. Mercury is probably the metal which can be most effectively purified: stretched single crystals of the purest possible mercury—needless to say, in solid form, which means at low temperature—show the typical banded appearance with great clarity (figure 8). The flattening in extension is illustrated in figure 10, which shows a single crystal of cadmium, extended by about 140 per cent., as seen from two directions at right angles (both normal to the axis of the wire).

Many of the observed phenomena can be explained by supposing that the deformation takes place by glide on particular sets of crystal planes, and in a particular crystal direction. The case of metals with hexagonal crystal structure is particularly simple and may be taken as an example. Here the so-called glide plane, on which slip takes place, is the hexagonal basal plane, which is unique, in contrast to, say, the octahedral planes in a face-centred cubic crystal, of which there are four equivalent sets. In the glide plane are three equivalent directions in which glide can take place, the digonal axes *OC*, *OD*, *OE* (figure 21): the one which will be operative in any case is that which is nearest to the projection *OA* of the wire axis on the plane, namely *OD* in the diagram. Glide will start when the shear stress on the glide plane resolved in the glide direction reaches a certain value *s*, the critical shear stress for the particular metal. Thus if *A* is the area of normal cross-section of the wire, *F* is the applied force in the direction of the wire axis, and χ and λ are the angles made by the glide planes and glide direction respectively with the axis of the wire, the condition for the start of plastic deformation is:

$$\frac{F}{A}\sin\chi\,.\,\cos\lambda = s.$$

In cubic crystals of the face-centred type the glide planes are the octahedral planes, such as *AED*, with three glide directions—*MN*, *PQ*, *RS*—in each, parallel to the triangular edges of the planes (figure 22). This leads to the possibility that a crystal may be so oriented that glide is equally likely to take place on two, or even on three, equivalent planes, as shown in figure 11 for a mercury single crystal and in figure 13 for a gold single crystal.

The critical shear stress *s* so defined varies from 25 gm wt/mm^2 to 1000 gm wt/mm^2 for a range of metals from cadmium to nickel, while the perfect crystal under shear stress should, theoretically, give perfect elasticity up to 50 per cent. shear strain and rupture at 100 kilo wt/mm^2 or more. Further, it is found experimentally that with single crystals very great work-hardening accompanies the permanent deformation. A particularly striking case is offered by silver, which, according to measurements made in my laboratory, begins to deform at a critical shear stress of 54 gm wt/mm^2, and breaks, after glide of 95 per cent., at 4500 gm wt/mm^2. Thus, as mentioned, generally speaking, single crystals show even greater departures from the simple theoretical picture than do polycrystalline metals. There is a further question that confronts us as soon as we look at a stretched single crystal, namely, why the glide occurs in layers, or 'packets' as they are often called, which means that certain planes of a set that in a perfect crystal would be equivalent are particularly favourable for glide. The thickness of these glide packets at atmospheric temperature is of the order of 1 μ (a thousandth of a millimetre), but it has been shown in my laboratory that the thickness increases very much at high temperatures. Figure 14 shows, for instance, the very coarse glide packets obtained with molybdenum at 1000° C. The glide in the very narrow regions separating the packets is very large: pictures taken with the electron microscope by Heidenreich and Shockley [7] show that with aluminium the laminae (invisible under the ordinary microscope) that make up the region of intense slip are about 200 A (roughly 70 atom diameters) thick, and may be displaced relatively to one another by 2000 A.

The abnormal weakness and the possibility of very large permanent deformations which, in general, characterize metal single crystals can be explained only by postulating flaws in the crystal structure, deviations from the perfect crystal lattice. Such deviations are now generally called 'dislocations'; to appreciate the fitness of the term it must be remembered that it signifies merely the movement of something from its right place. The simplest dislocation in a lattice, of a kind invoked by G. I. Taylor in his theoretical work on metal strength, can be illustrated by a two-dimensional case, represented in figure 23. The top rows symbolically represent a nearly perfect lattice. In the seventh row from the top there is a local expansion of the atomic spacing, resulting in a misfit, or dislocation, centred on the spot marked by the arrow, with a corresponding irregularity of the surface of the crystal, represented by the atoms to the extreme left. Owing to the modification of the atomic forces caused by the abnormal positions, the marked atom is less firmly held than is the case in the normal lattice, and it is possible to move it sideways by a comparatively small horizontal shear, bringing the neighbouring atoms with it, so that the next atom becomes the centre of the dislocation, moves in its turn under the small shearing stress, and so on, the dislocation passing along a horizontal line.

To illustrate the passage of a dislocation, which is a fundamental feature of all modern theories of the deformation and hardening of metal crystals, I made some time ago a dynamic model, illustrated in figure 6 [8]. The white disks in the photograph are the ends of wooden cylinders, about three inches in diameter, the lower row being fixed and the upper row resting on them, each one in a (gravitational) potential hollow. The cylinders of the upper row are also connected by a black

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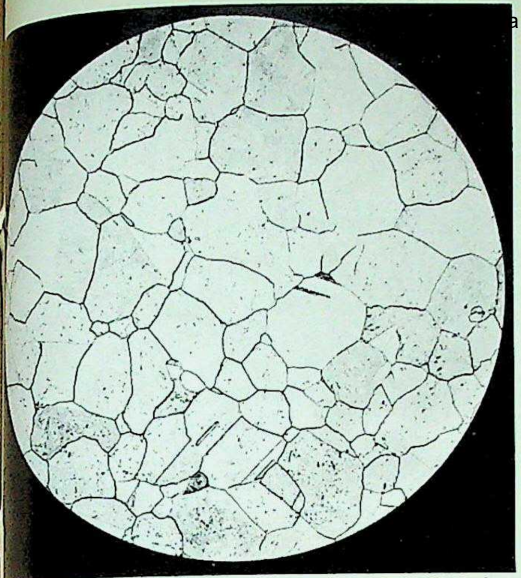


IGURE 1 – *Polycrystalline lead with grain boundary* ch. (× 9)
(*By courtesy of the British Non-Ferrous Metals Research Association.*)

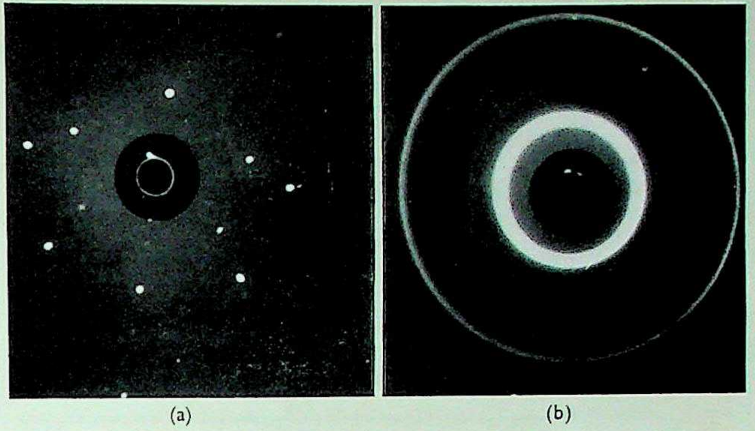
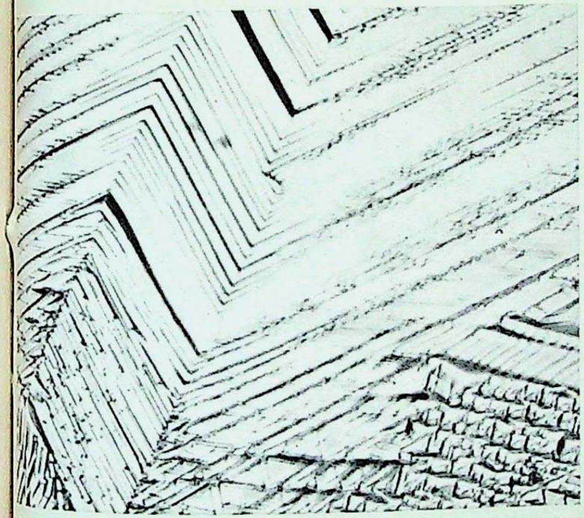

(a) (b)

FIGURE 2 – *Back-reflection X-ray photograph of a gold wire:* (a) *Single crystal,* (b) *polycrystalline state.*
(*Photograph by Dr C. Henderson, Carey Foster Laboratory.*)



IGURE 3 – *Silver thermally etched in oxygen.* (× 1500)
(*Photograph by Mr R. King.*)

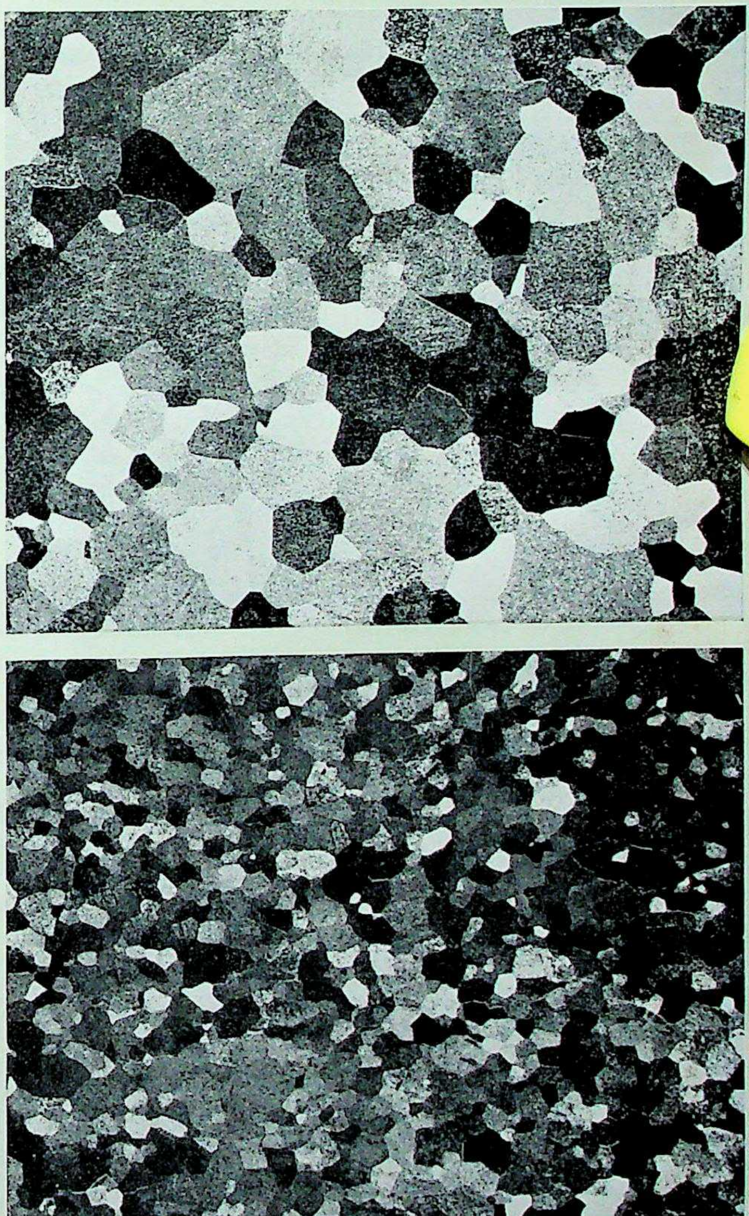


FIGURE 5 – *Aluminium containing 0·5 per cent. silver: same metal, two different grain sizes.* (× 10)

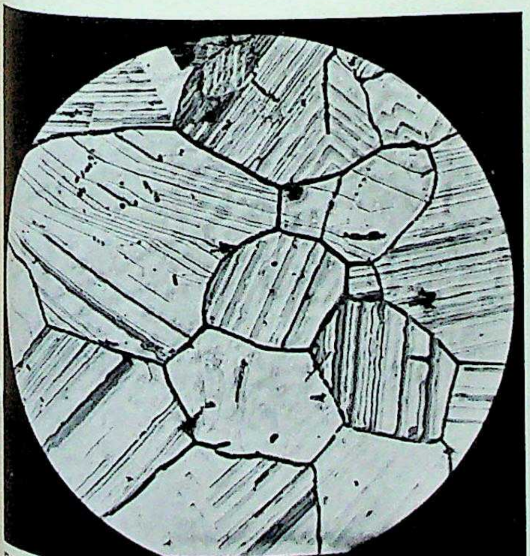


FIGURE 4 – *Silver thermally etched in air.* (× 540)
(*Photograph by Mr L. Walden, Carey Foster Laboratory.*)

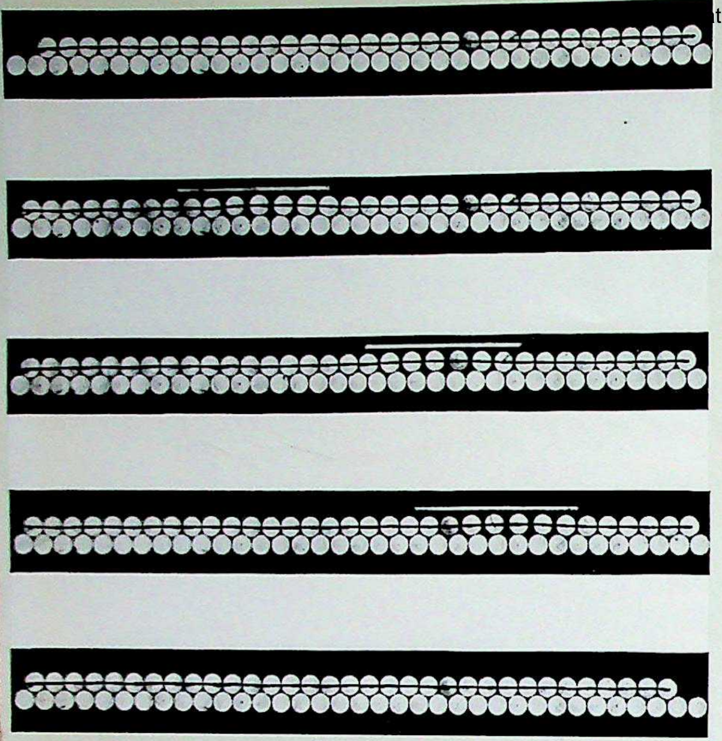


FIGURE 6 – *Model to illustrate propagation of a line dislocation.*

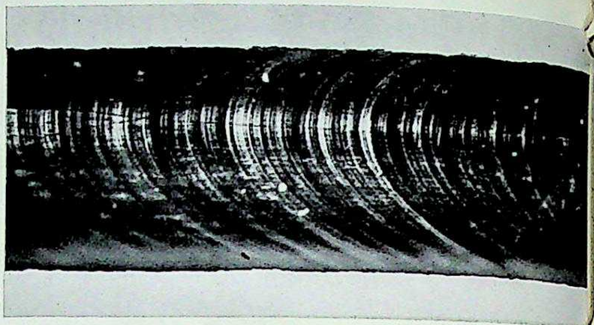
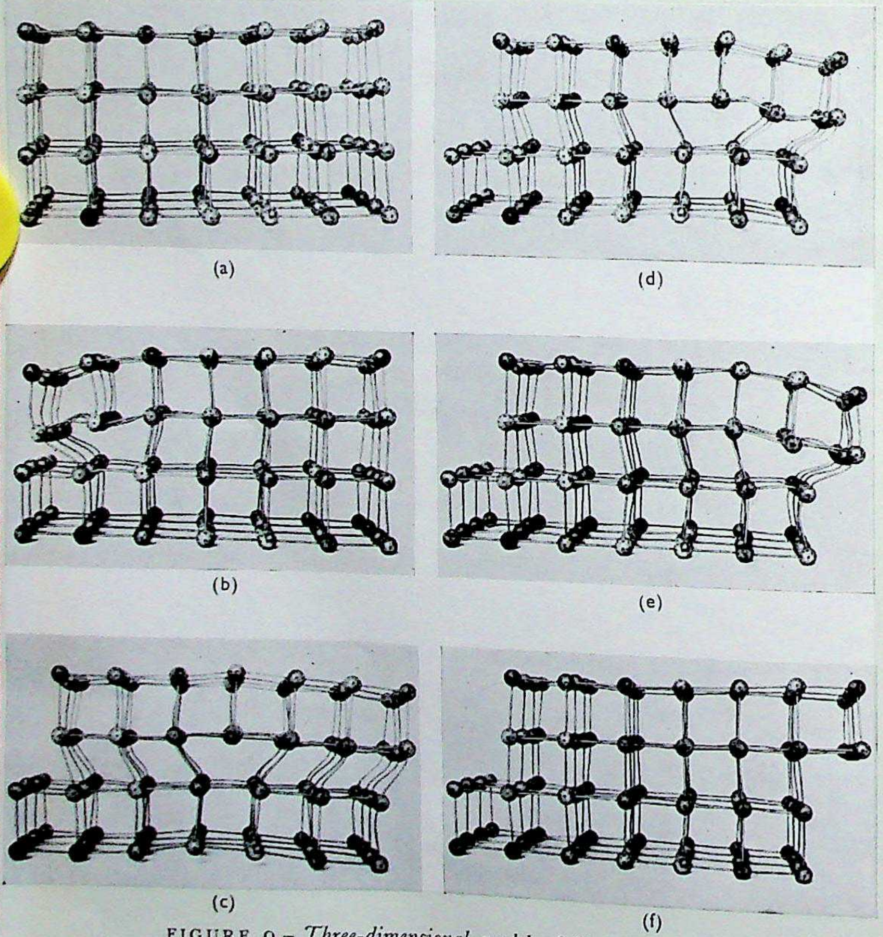


FIGURE 7 – *Cadmium single crystal, extended by 40 per cent.* (× 30)

(Photograph by Mr L. Walden, Carey Foster Laboratory.)



(a) (d) (b) (e) (c) (f)

FIGURE 9 – *Three-dimensional model of line dislocation.*

(By courtesy of Dr B. A. Bilby and The Institute of Metals.)

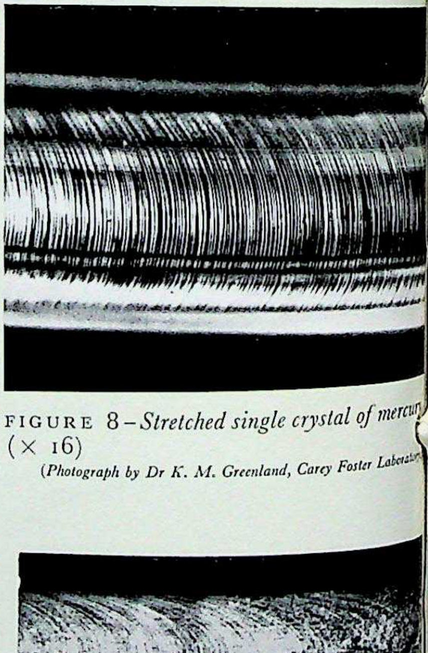


FIGURE 8 – *Stretched single crystal of mercu* (× 16)

(Photograph by Dr K. M. Greenland, Carey Foster Labora

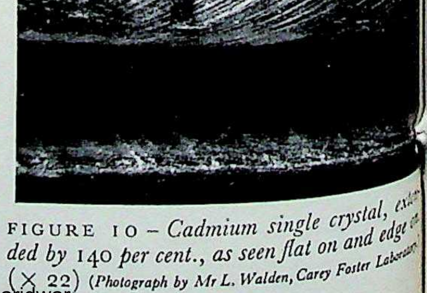


FIGURE 10 – *Cadmium single crystal, ext ded by 140 per cent., as seen flat on and edge o* (× 22) *(Photograph by Mr L. Walden, Carey Foster Labora*

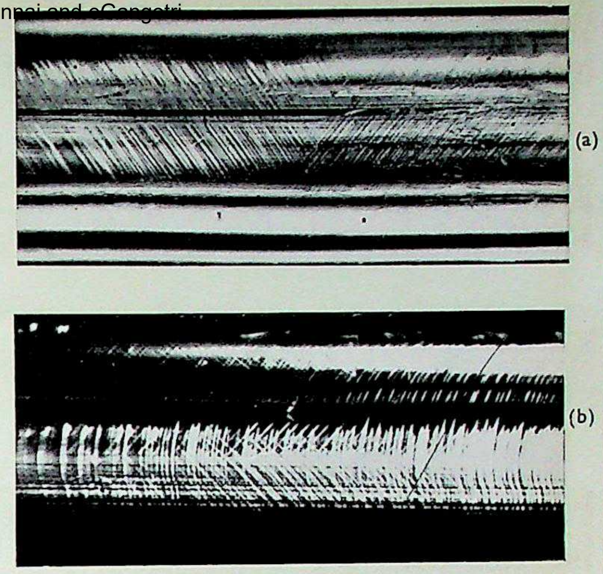


FIGURE 11 – (a) *Double glide,* (b) *triple glide, in mercury single crystal.* (× 16)

(Photograph by Dr K. M. Greenland, Carey Foster Laboratory.)

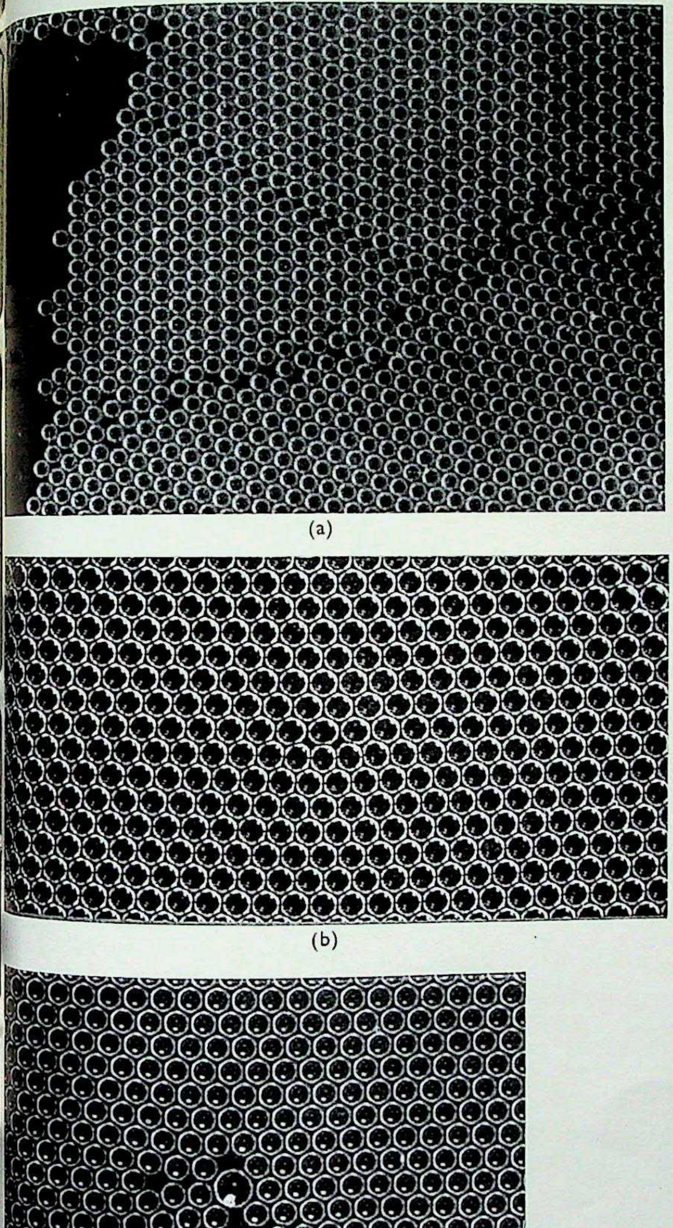


FIGURE 12 – *Bubble model:* (a) *A grain boundary,* (b) *a dislocation, in middle of picture,* (c) *effect of a larger foreign atom.*

(By courtesy of Sir Lawrence Bragg, Dr J. F. Nye, and The Royal Society.)

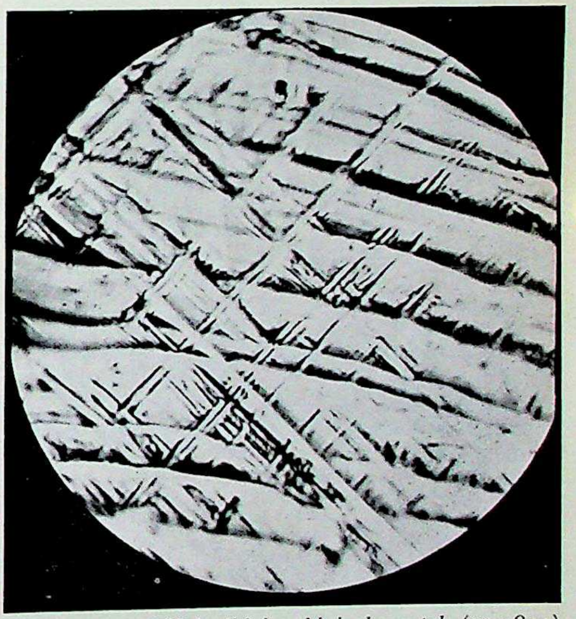


FIGURE 13 – *Triple glide in gold single crystal.* (× 1800)

(Photograph by Dr C. Henderson, Carey Foster Laboratory.)

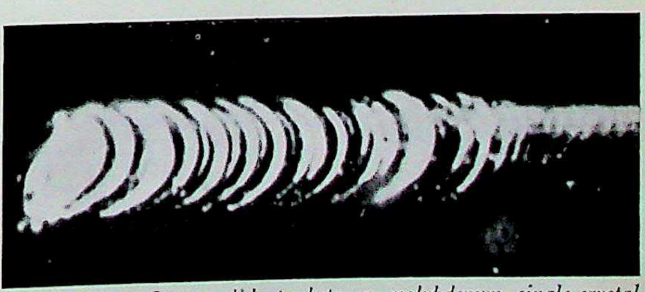


FIGURE 14 – *Coarse glide packets on molybdenum single crystal at* 1000° *C.* (× 65)

(Photograph by Dr L. C. Tsien and Dr Y. S. Chow, Carey Foster Laboratory.)

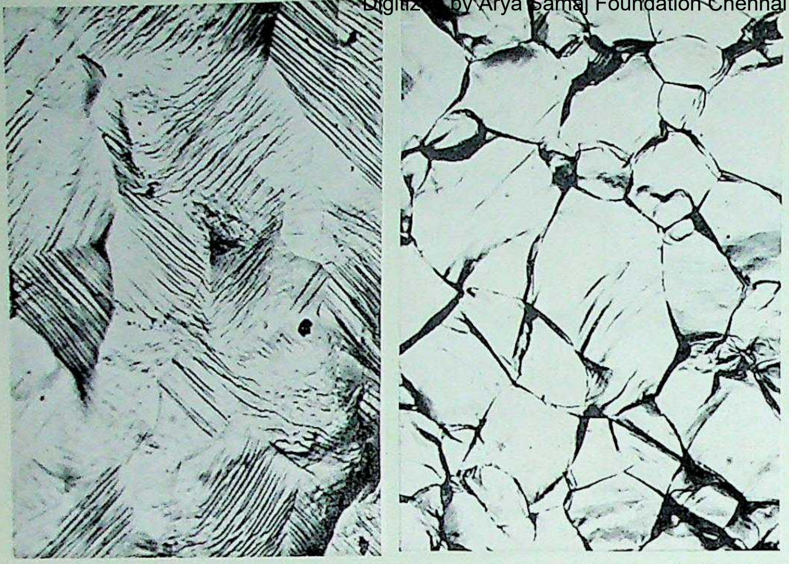
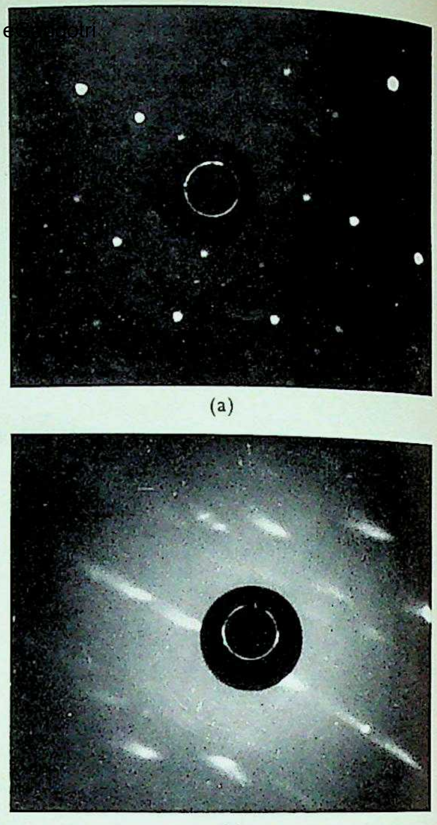


FIGURE 15 – *Aluminium (left) after 9 per cent. rapid strain at 200° C, (right) after 8 per cent. rapid strain at 500° C.* (× 100)

(*By courtesy of Dr W. A. Wood and Mr W. A. Rachinger, and the Institute of Metals.*)



(a)

(b)

FIGURE 16 – *Laue back-reflection photographs of silver single crystal,* (a) *unstretched,* (b) *highly stretched.*

(*Photograph by Dr C. Henderson, Carey Foster Laboratory.*)

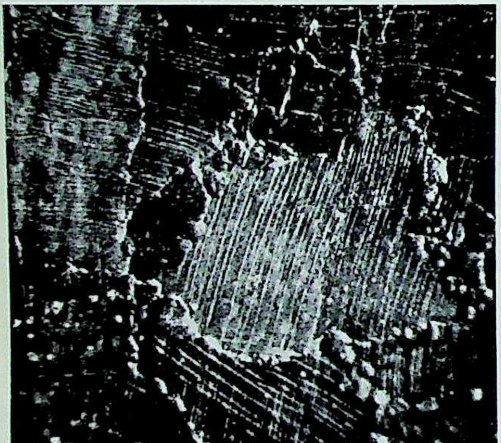


FIGURE 17 – *Slip lines in grains of polycrystalline lead.* (× 60)

(*Photograph by Mr K. H. Jolliffe, Carey Foster Laboratory.*)

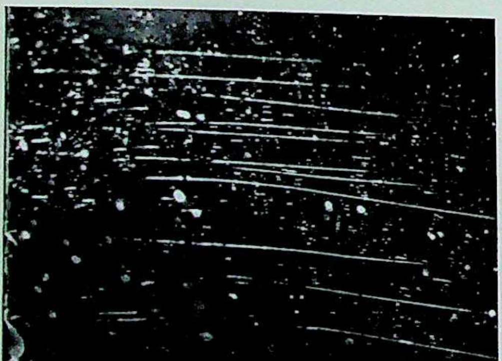


FIGURE 18 – *Griffith cracks on Pyrex glass surface revealed by attack of sodium vapour.* (× 14)

(*Photograph by Professor E. N. da C. Andrade and Dr L. C. Tsien.*)

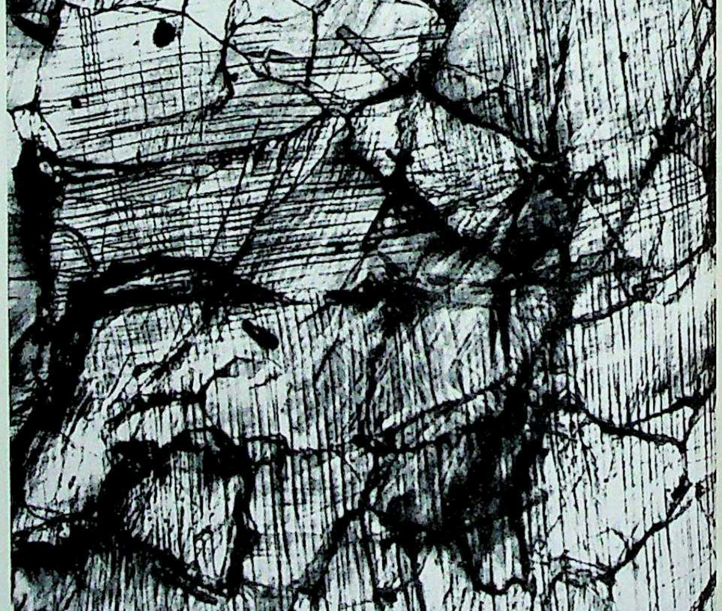


FIGURE 19 – *Slip in recrystallized lead, showing old boundaries.*

(*Photograph by Mr K. H. Jolliffe, Carey Foster Laboratory.*)

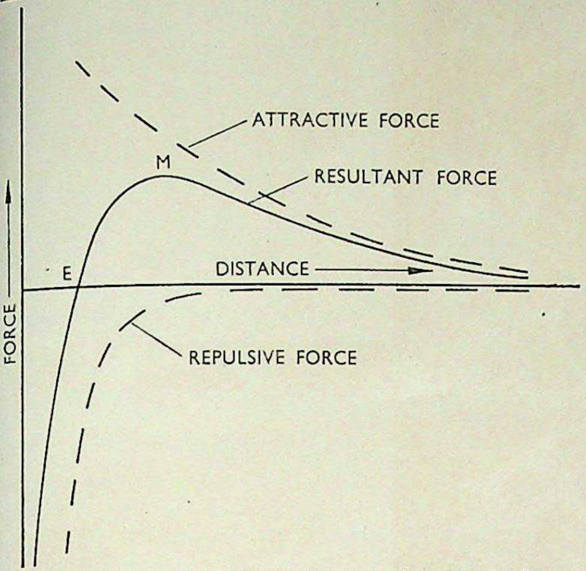


FIGURE 20 – *Diagram to illustrate interatomic forces.*

elastic band, attached to the centre of each cylinder, to represent horizontal interatomic forces. When the upper row is compactly spaced, as in the topmost picture, it is impossible by ordinary pushing to make it travel by one spacing over the lower row: this would involve making all the cylinders mount simultaneously over the crests of the hollows in which they lie. Let us now make a dislocation, as shown by the widened spacing under the white line in the second picture from the top. The middle cylinder of the dislocation is not in a hollow at all, and it is very easy to move it one to the left, which makes the centre of the dislocation move one to the right. The third and fourth pictures show the travel of the dislocation, produced by passing the hand over the cylinders. In the lowest photograph, the dislocation has travelled to the end and the whole row is displaced by one spacing.

Dr Bilby [9] has made some excellent three-dimensional models to illustrate different types of dislocation.[1] The series representing the travel of the simple line dislocation which we have been considering is given in figure 9, where *a* is the perfect lattice; *b* is the lattice with a line dislocation near the left-hand side; *c*, *d*, and *e* are various stages of the travel; and *f* is the final state caused by the passage of the dislocation.

Sir Lawrence Bragg and Dr Nye [10] have perfected a spectacular way of illustrating many properties of metal crystals. Each atom is represented by a single bubble in 'rafts' of very uniform small bubbles produced by a special device. In figure 12 are examples of the bubble model, (*a*) showing a grain boundary, (*b*) a dislocation, and (*c*) the disturbance produced in the lattice by a large (foreign) atom.

This conception of glide by travelling dislocations explains the softness of metal single crystals, why polycrystals are harder, and why, in general, a metal with very fine grains deforms less readily than one with coarser grains. For the propagation of a dislocation a fairly regular structure is necessary, the centre of disturbance being handed on

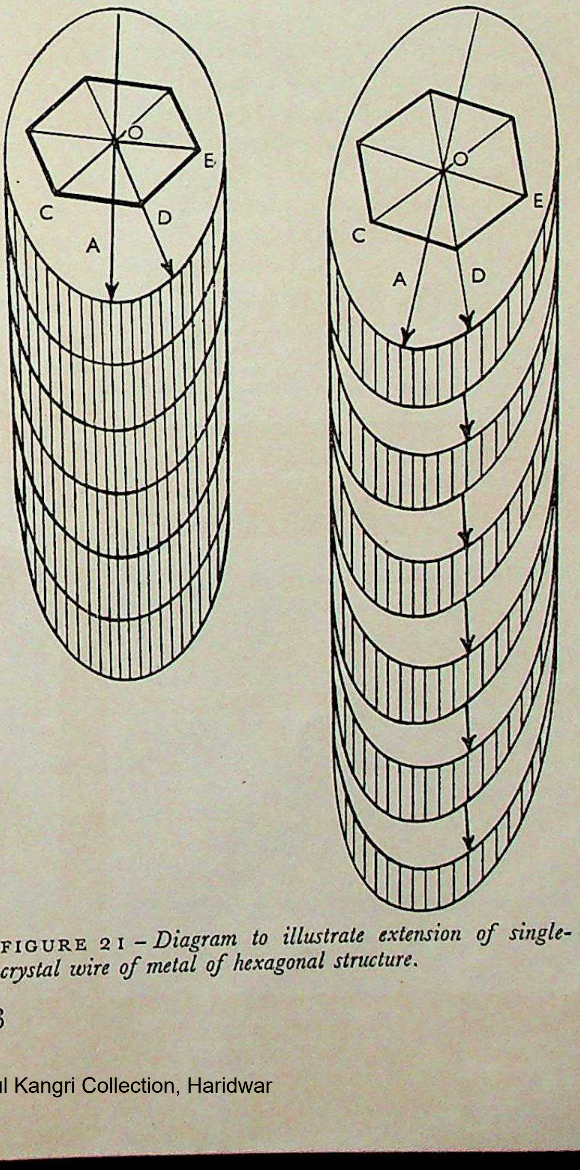


FIGURE 21 – *Diagram to illustrate extension of single-crystal wire of metal of hexagonal structure.*

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[1] The dislocation represented by the two-dimensional case is, of course, the same in a three-dimensional crystal, in every plane parallel to the paper, so that, as it passes, the whole upper half of the crystal is displaced with reference to the lower half of the crystal. It is called a line dislocation. If, in the three-dimensional case, only a small length of the crystal, considered at right angles to the paper, as distinct from the whole width, is shifted with reference to the crystal below, a more complicated form known as a screw dislocation may arise (see e.g. A. H. Cottrell in *Progress in Metal Physics*, 1949). Curved line dislocations have also been considered by the theorists.

unchanged from one spot to the next. The break in the regular crystal structure at the grain boundary holds up the propagation of the dislocation. The slip lines within the grains of a polycrystalline metal, and their termination at the boundary, are well shown in figure 17. Any lack of homogeneity in the structure may also harden the metal by arresting the run of the dislocation. Thus the hardening of single crystals by impurities can be explained as due to local strains produced by stranger atoms, as illustrated in figure 12 (*c*), which check the run of the dislocations. The mechanical effect of precipitation from a supersaturated solid solution of particles which do not fit into the lattice—the so-called precipitation-hardening—has been attributed to these local strains, and Mott and Nabarro [11] have worked out a mathematical theory of the phenomenon.

One great problem of the single-crystal state is the marked hardening which always takes place with permanent strain. The critical shear stress increases as the crystal is deformed by glide, at temperatures that are not too high—and, as a rough rule, it is the ratio of the prevailing temperature to the temperature of melting that is effective when we speak of high or low temperatures. There is strong evidence that this hardening is connected with local break-up of the single-crystal structure. It is found that with strained crystals we no longer get distinct Laue spots, such as are shown in figures 2*a* and 16*a*, but that each spot becomes smeared out into a line. This extension of spots, due to the existence in the crystal of planes rotated through small angles from the normal, is called asterism: an example is given in figure 16*b*. It has been shown in my laboratory that the hardening is proportional to the spread of angle indicated by the asterism. The hardening of single crystals under strain is, then, due to the fact that they lose something of their single-crystal structure, with a consequent creation of obstacles to the run of dislocations.

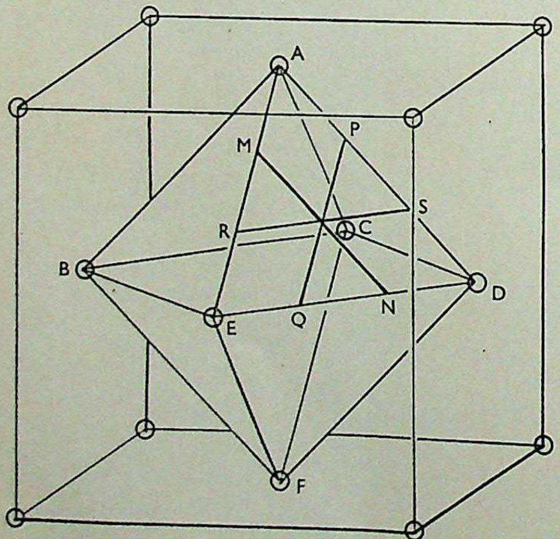

FIGURE 22 – *Glide elements of metal of face-centred structure.*

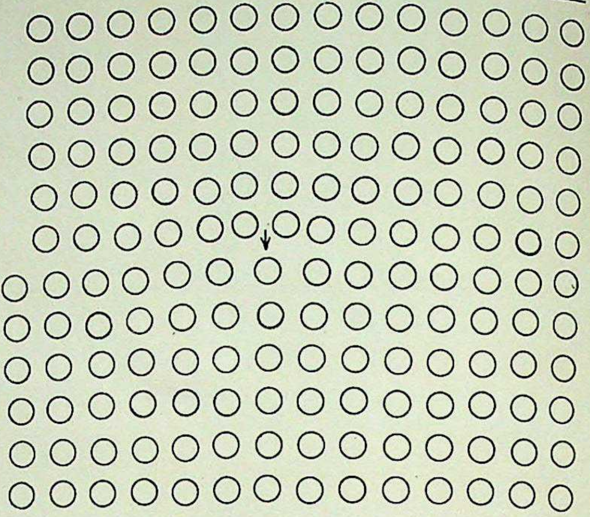

FIGURE 23 – *Diagrammatic representation of line dislocation.*

The effect described by Rehbinder of a surface-active agent (such as oleic acid) in promoting flow, which he attributed to penetration of the liquid into minute cracks, seems to be due to the disintegration of thin films of surface oxide, which inhibit slip. Randall and I have found that the flow of ordinary single crystals of cadmium is enhanced by the contact with the surface of electrolytes containing cadmium ions, but that if the surface of the wire is cleaned by heating it *in vacuo* until considerable vaporization has taken place, there is no such effect [12]. Heating a cadmium single-crystal wire in air so as to produce light surface oxidation puts up the critical shear stress. To be brief, a range of observations indicates that it is possible that most, if not all, of the dislocations start at the surface, and that any kind of oxide contamination tends to hinder their effectiveness.

An effect which must be taken into account in many problems of metal strength was brought into prominence by A. A. Griffith. The mathematical theory of elasticity shows that in a solid the stress at the end of any crack or fissure is much above the average. In particular, for a crack of elliptic cross-section, of major and minor axes a and b respectively, the maximum stress, in the neighbourhood of the greatest curvature, is $\sigma(1 + 2a/b)$, where σ is the stress a long way off. Hence, in particular, anything in the nature of a surface crack may lead to a very high local stress, provided—and this is often forgotten—that the material may be treated as a perfect elastic solid. Local plastic yielding will, of course, completely invalidate the calculation. The existence of microscopically invisible surface cracks has not been proved in metals, but Andrade and Tsien [13] have shown that they can be revealed in glass by the attack of sodium vapour and by other means (see figure 18). Such microcracks are

stresses as those produced by, say, rolling, are extremely difficult to treat theoretically. No attempt at a survey can be made here, but something may be said about a problem that has recently assumed great engineering importance, namely the flow of metals under high stresses and temperatures. The gas turbine in all its forms is dependent upon steels that, at the temperatures in question, must not systematically creep under the stresses produced by the high speeds of revolution. Even in the practical utilization of nuclear energy the creep of metals is involved: thus, treating of the power-level of an atomic pile, Sir John Cock-

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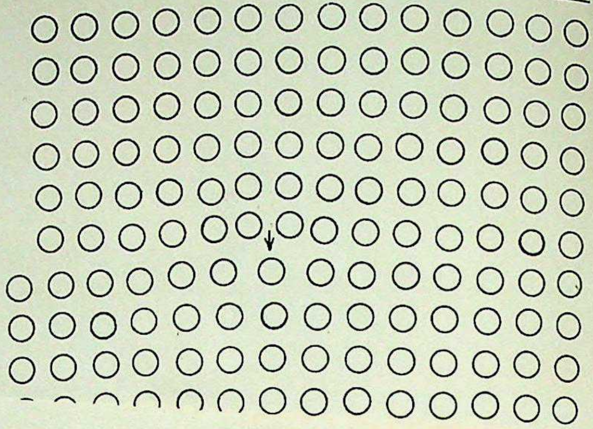

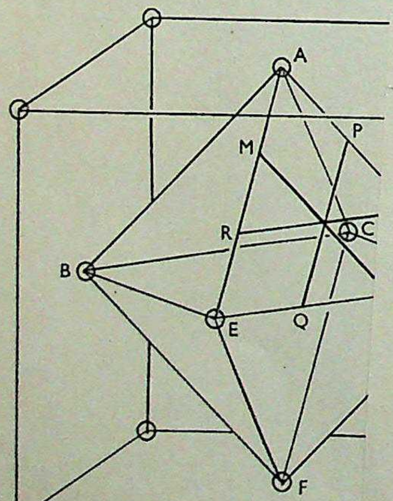

FIGURE 22 – *Glide elements of meta*
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axes a and b respectively, the maximum stress, in the neighbourhood of the greatest curvature, is $\sigma(1 + 2a/b)$, where σ is the stress a long way off. Hence, in particular, anything in the nature of a surface crack may lead to a very high local stress, provided—and this is often forgotten—that the material may be treated as a perfect elastic solid. Local plastic yielding will, of course, completely invalidate the calculation. The existence of microscopically invisible surface cracks has not been proved in metals, but Andrade and Tsien [13] have shown that they can be revealed in glass by the attack of sodium vapour and by other means (see figure 18). Such microcracks are referred to as 'stress-raisers'; if of atomic narrowness they may lead to very large local stresses. Larger, microscopically visible, microcracks play a great part in fatigue failure of industrial metals. If Griffith cracks exist in the surface of single-metal crystals and are the origin of dislocations, the large effect of such things as the oxide coatings can be easily understood, since they may effectively heal such narrow fissures. The distribution of Griffith cracks of varying severity in the surface may help to account for the existence of the glide packets, to which attention has already been directed, rather than uniform glide on all crystallographically equivalent planes. This is a complicated question, but there is much evidence for faults spaced at something of the order of 1 μ in metal single crystals. The striations in the grains of the silver crystals of figures 3 and 4, revealed by thermal evaporation, have, for instance, approximately this spacing, as have the separations of the slip bands in most metals at temperatures not too high, and also certain markings revealed by the thermal etching of single crystals of cadmium [4]. Straumanis has shown that cadmium crystals formed from vapour (and in other ways) are laid down in steps of thickness of the order of 1 μ. The stress-strain relationship for single crystals, even those with only one system of glide planes, is a complicated matter, to explain which the interaction of local stress concentrations caused by lattice irregularities has been invoked. In short, the mechanical behaviour of single crystals of metals, even of spectroscopic purity, can be explained only by a system of faults in the crystal structure.

When the behaviour of the single crystal under comparatively simple stress systems is so complicated, it is not surprising that the problems of the practical metallurgist, dealing with polycrystalline systems of many components under such involved stresses as those produced by, say, rolling, are extremely difficult to treat theoretically. No attempt at a survey can be made here, but something may be said about a problem that has recently assumed great engineering importance, namely the flow of metals under high stresses and temperatures. The gas turbine in all its forms is dependent upon steels that, at the temperatures in question, must not systematically creep under the stresses produced by the high speeds of revolution. Even in the practical utilization of nuclear energy the creep of metals is involved: thus, treating of the power-level of an atomic pile, Sir John Cockcroft says: 'The decreasing creep-strength of aluminium with increasing temperature would probably limit surface temperatures to about 350° C.' Hence the laws of creep have considerable practical as well as theoretical significance.

Most experiments on creep have been carried out with cylindrical rods under tension. If the stretching force is applied by a constant load, then, since the cross-sectional area diminishes as the rod extends, the stress increases with time, which complicates matters. Various devices have been contrived for diminishing the load automatically in such a way as to maintain the stress at a constant value [14]. Under these conditions, the curves shown for lead (figure 24) are typical of a range of pure metals. At a low temperature (− 180° C) there is a large immediate extension, followed by an increase of length at a very slow rate, which decreases and ultimately becomes zero. At a somewhat higher temperature (− 78° C) the creep is more marked but ultimately becomes vanishingly small. At room temperature, the rate of creep is much larger and the rate approaches a finite constant, while at high temperature (160° C) the main part of the creep curve exhibits a constant rate. The curves shown in figure 24 are for short times of flow only, but the laws now to be given have been verified over much longer durations. While the curves shown are for lead, they are representative for all the pure metals systematically tested under conditions in which recrystallization does not take place: thus the creep behaviour of iron at 450° C resembles that of lead at 16°, and the creep behaviour of iron at 16° resembles that of lead at − 180° C.

It is found that the behaviour can be represented by the equation:

$$l = l_0(1 + \beta t^{1/3})e^{\kappa t},$$

where l_0, β, and κ are constants. The exponential term represents flow at a constant rate per unit

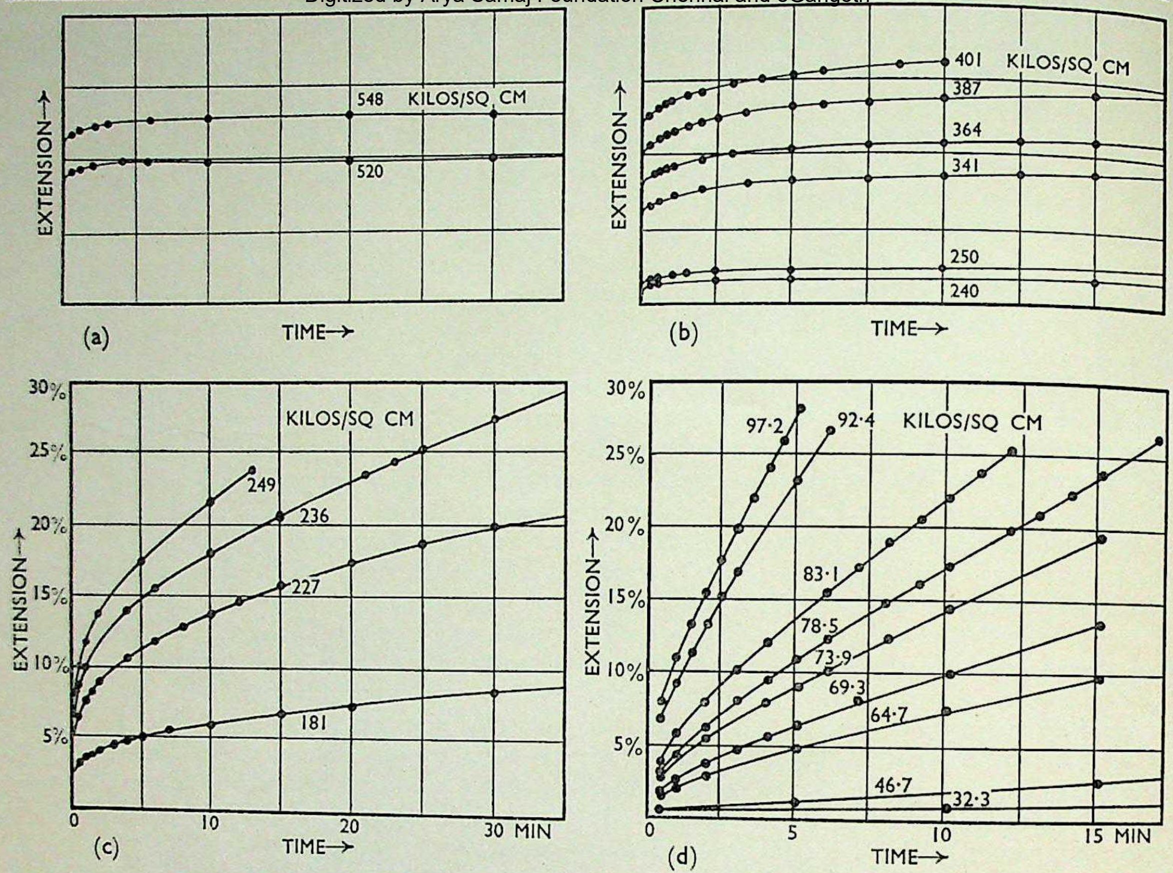

FIGURE 24 – *Creep in polycrystalline lead at various temperatures and stresses:*

(a) – 182° C, *no permanent flow.*
(b) – 78° C, *no permanent flow.*
(c) 17° C, *transient flow and permanent flow.*
(d) 160° C, *permanent flow predominant.*

length, and is caused by the fact that the length flowing increases during the experiment: thus if $\beta = 0$,

$$\frac{1}{l}\frac{dl}{dt} = \kappa.$$

The importance of this analysis is that it divides the flow into two parts: one part proportional to $t^{\frac{1}{3}}$, that is, diminishing in rate very rapidly, and the other proportional to t, that is, proceeding at constant rate. The part measured by β is called the β flow or transient flow; that represented by κ is the quasi-viscous or permanent flow. At low temperatures $\kappa = 0$. In this connection 'low temperature' means, as has been already pointed out, temperature low compared to the melting point.

It is now generally accepted that the transient flow is connected with slip within the grains and the permanent flow with relative movement of grains [15]. Thus Hanson and Wheeler, working with aluminium, found that, at low temperature and rapid deformation (favourable to transient flow), well-defined slip lines terminating at the boundary, such as are exemplified in figure 17, appeared within the grains, while at high temperature and slow deformation (favourable to permanent flow) the grain boundaries became much emphasized, and eventually intercrystalline cracks appeared. This is well shown by some photographs, also of aluminium, due to Wood and Rachinger [16]. Figure 15*a* is after 9 per cent. rapid strain at 200° C, which may be reckoned a low temperature for aluminium: the slip lines in the grains are well seen. Figure 15*b* is after 8 per cent. rapid strain at 500°, which is a high temperature: the boundaries are broad and dark, but there are few slip lines. It was earlier shown [14] that the transient flow was connected with a rotation of the axes in the grain, which is in accordance with the slip on crystal planes. The $t^{\frac{1}{3}}$ law has apparently great generality, but no fully satisfactory theory of it is yet established. The flow of metals has recently been studied in my laboratory under pure shear, and in these conditions the $t^{\frac{1}{3}}$ law has been fully confirmed. The permanent flow does not take place with the particular system of stressing used, a fact that accords well with the view that attributes it to intergranular movement.

In many cases, the creep in metals is complicated by the fact that recrystallization takes place during the flow, especially with the steels used in high-temperature engineering. It also takes place with very pure lead during flow. In the process of recrystallization, certain small undistorted grains tend to enlarge their domain at the expense of others, with consequent movement of boundaries. Figure 19 is a striking photograph taken in the course of work which we have been carrying out under pure shear. The crystal boundaries so plainly marked are the original boundaries, brought into prominence by etching, but extensive recrystallization has taken place, as shown by the slip lines, running in some cases right across the picture. These indicate that one crystal domain now covers most of the photograph, the apparent grain boundaries being only the old surface markings—old shallow ditches across which the plough has been driven now that the original small fields have been incorporated in one farm. During recrystallization, flow is enhanced: the main features of flow under these conditions are now satisfactorily explained.

Needless to say, this brief account does not even mention many important branches of the subject. The study of the basic mechanical properties of metals is one that has sprung into prominence in the last twenty years or so, and at the present time it is being actively pursued in Britain in the universities of Cambridge, Bristol, Birmingham, and London, as well as in many government and industrial laboratories. In 1934, the date of the international conference on the solid state of matter (London), there was hardly a book devoted to the physical aspects of metal strength. In 1935 appeared Schmid and Boas's *Kristallplastizitat*: since then there have appeared in England, Germany, France, and the United States a number of significant books dealing with what is often called metal physics, regardless of the fact that this term should include the thermal, optical, and electrical properties as well as the mechanical properties. After long neglect, the interest and importance of seeking some explanation of the most obvious properties of the metallic state, many of which have been known to craftsmen for generations, are becoming realized. The atomic nucleus, of course, remains supreme, but the way in which metallic atoms hold together and modify their assemblies under the rough treatment to which they are subjected has its attraction as a subject of study.

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Land erosion

SIR CYRIL FOX

The process of erosion is of great importance in the geological history of the world, for it is one of the main factors bringing about the immense changes which slowly alter the whole configuration of the earth's crust. Recently, man's activities have sometimes resulted in local erosion so rapid as to turn great tracts of fertile land into deserts. Knowledge of the mechanism of erosion is therefore of great practical, no less than of theoretical, value.

INTRODUCTION

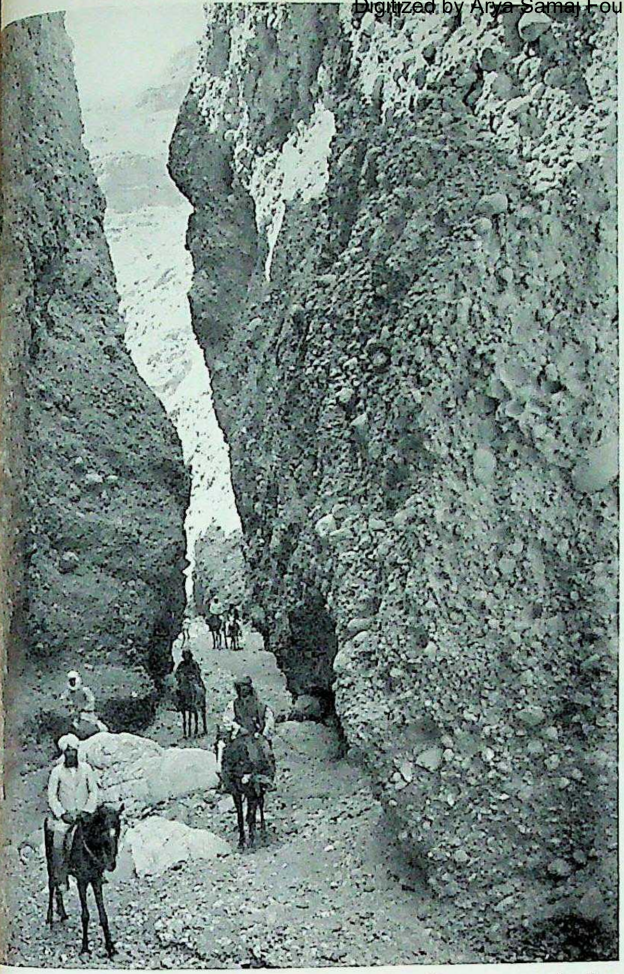
The word erosion has been used for the last 120 years by geologists to denote those natural processes which wear or eat away the substance of the earth's crust. The term covers a wide range of physical and chemical actions—removal of soluble matter, chemical changes, disintegration by frost or rapid changes of temperature, attrition by dust-charged winds, scouring by silt-laden currents, alternate impact and suction by storm waves, landslides, and so on. During the last forty years the question has arisen whether the term erosion should not cover agents acting more quickly, such as volcanic explosions, and man's activities in the removal of minerals. All aspects of one of the most important studies of the earth's crust are a fundamental concern of the field geologist.

GORGES AND CANYONS

It is often difficult to explain why a river has cut a gorge when, from existing topography, it might have made an easy detour. The rate of erosion is influenced by the nature and structure of the rocks, and by any regional uplift or sinking which may be in progress to increase or decrease the gradient of the river. The most spectacular and greatest example is the Grand Canyon of the Colorado River in Arizona, estimated at 300 miles long, with an average depth of 0·65 miles and width of 10 miles, figures which provide a measure of the volume of rock removed by stream erosion. The strata are, for the greater part, relatively soft Palaeozoic sandstones, shales, and limestones, which slope gently to the south-west, with some Pre-Cambrian (Algonkian) and Archaean (gneisses) in the bottom (floor and sides). The Rocky Mountain uplift has kept the tilt to the south-west and thus maintained the gradient of the Colorado River in that direction. However, it is clear that the silt-laden waters of the river have been the chief cutting agents in excavating the Grand Canyon. At present, the silt carried by the Colorado River into Lake Mead is estimated at 0·01 cubic miles annually. If this can be taken as an average also for the past, the gorge is approximately 200,000 years old (the figure is so large that one extravagant guess is as good as another). In contrast to this, the Niagara River, as it races over the limestone (Silurian) to the American and Canadian Falls from Lake Erie, is clear and siltless. With the drop of 165 feet into the swirling waters below, and the action of fallen blocks of stone, a great scour proceeds in the Medina shales, which leads to the undermining of the overlying strata and the regression of the falls. The Palaeozoic strata dip gently south-west, and the gorge below the falls is now nearly 7 miles long. The advance of the gorge from Lake Ontario has been computed at about 2 feet a year, so that the falls may be roughly 20,000 years old. It should be mentioned, however, that an uplift to the north-east has been in progress in this region since the Canadian (Pleistocene) ice sheet slowly retreated and unloaded its weight from the earth's crust over Ontario. This movement would tend to reduce the gradient of the Niagara River, but it is doubtful if it has seriously affected the rate of regression of the falls.

COAST EROSION

Many cyclones from the Bay of Bengal, travelling towards the Ganges Delta just ahead of a high tide, have forced a storm wave 40 feet high into the estuaries and over the low-lying country. The cyclone of 1864 left a vessel of 2185 tons high and dry on Shalimar Point, near Calcutta. However, it is the 'backwash' or retreating waters which have destroyed crops and swept away thousands of people and cattle. The Backerganj cyclone of 1890 was followed by famine and disease. The retiring wave appears to converge towards the position of the 'swatch of no ground,'



URE 1 – *A Baluch defile near Mach, showing the canyon cut by floor rs assisted by a big boulder which acted as a borer.* (*Photograph by S. Fox.*)

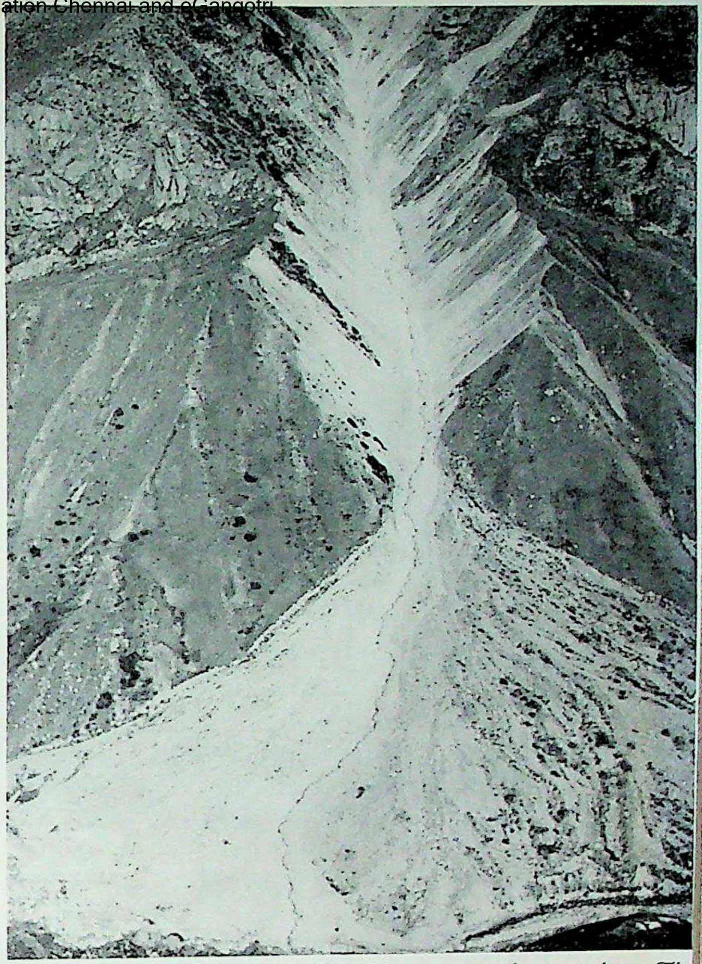


FIGURE 2 – *Typical V-notch produced by stream erosion on a slope. The water has carried out a deltaic fan of débris.* (*Photograph by J. B. Auden.*)

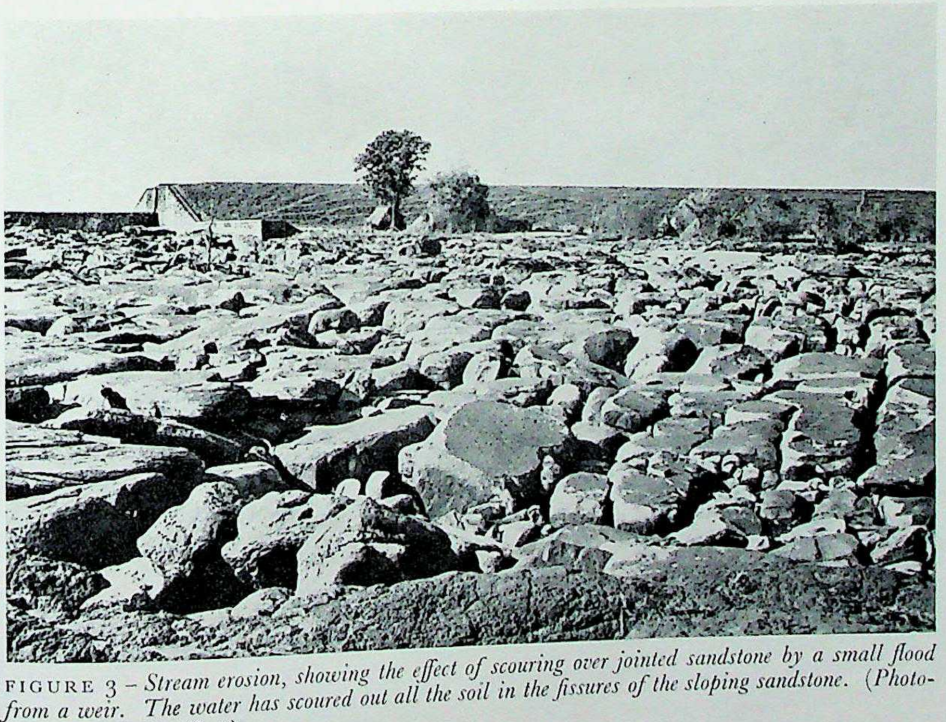


FIGURE 3 – *Stream erosion, showing the effect of scouring over jointed sandstone by a small flood from a weir. The water has scoured out all the soil in the fissures of the sloping sandstone.* (*Photograph by W. D. West.*)

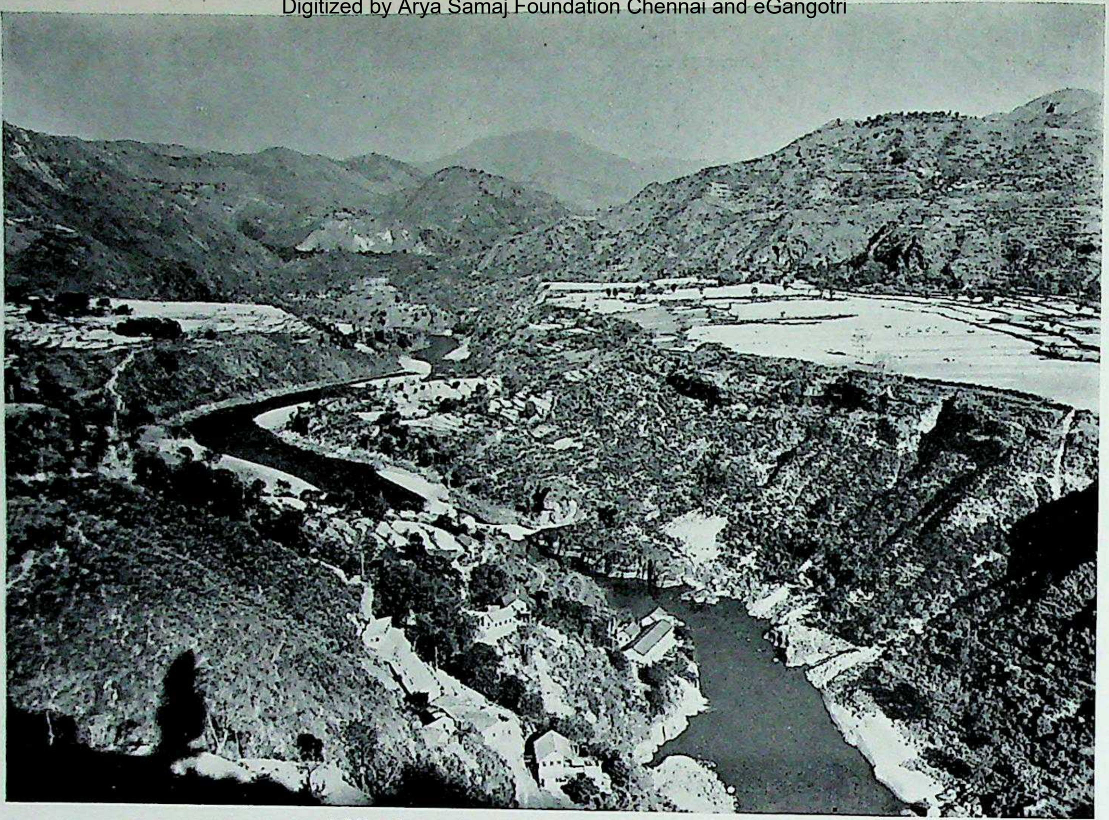


FIGURE 4 – *A Himalayan river, the Sutlej at Chabar, north of Simla, showing the river re-excavating two older river terraces. (Photograph by W. D. West.)*

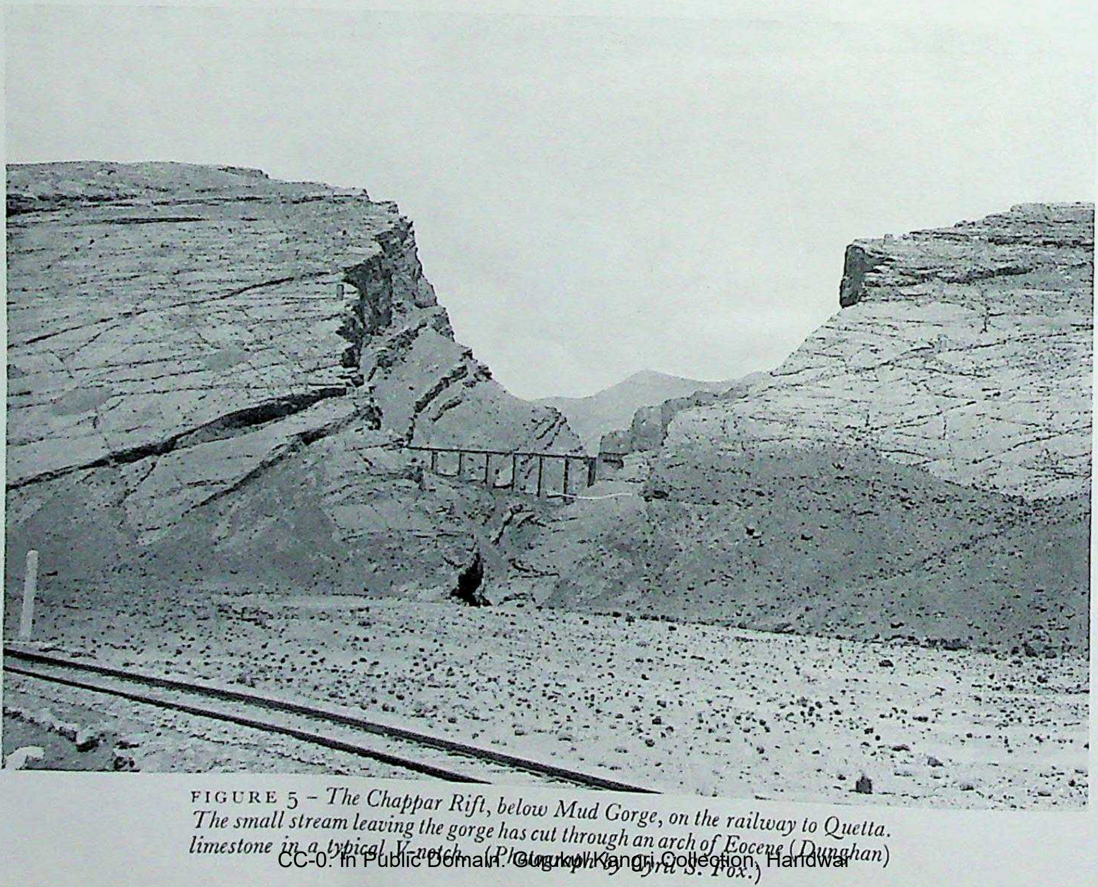


FIGURE 5 – *The Chappar Rift, below Mud Gorge, on the railway to Quetta. The small stream leaving the gorge has cut through an arch of Eocene (Dunghan) limestone in a typical V-notch. (Photograph by Cyril S. Fox.)*

off the delta, and it is believed that the deep water there is due to scouring by such flood waters. The erosion of tidal currents and storm waves has long been demonstrated near Hilderthorpe in Bridlington Bay on the Yorkshire coast, England, but the severity of the action appears to be due to lack of sufficient hard material. The glacial boulder clays exposed contain too few boulders to furnish a protective or storm beach, such as the famous Chesil Bank on the Dorset coast. This shingle bank extends as a natural feature for 18 miles, from near Bridport along the coast to Abbotsbury, and so to Portland Island, where the quartzite pebbles disappear into the sea, having been moved along 25 miles by the surge and scour of the tides and waves from Budleigh Salterton, under Lyme Bay, to near West Bay, and then along the Chesil Bank to Portland Island. At Budleigh Salterton the pebbles fall from the cliff on to the beach, which is a protective apron to the cliffs. The material in the pebble beds (Triassic) was derived from a Palaeozoic (Ordovician) sandstone, so that the original pebbles were produced more than 150 million years ago—and are being utilized again—from material eroded from older rocks 400 million years ago.

LANDSLIPS AND MUDSLIDES

In certain arid regions where a wide valley is filled with an alluvial deposit of mud and gravel, a sudden heavy fall of rain may convert the material into a liquid which moves like a stream of lava and flows for considerable distances. The Mud Gorge in Baluchistan, named after the trouble encountered by early railway engineers, is famous for pyritiferous shales (Eocene) which, after weathering, become of the consistency of liquid mud. These are extreme cases of soil and subsoil on hillsides becoming waterlogged, and losing the cohesion which enabled the mass to stand at a high angle of repose. In the case of the Gohna Landslip in Garhwal (Himalayas), the hillside was composed of crumpled dolomitic limestone and pyritiferous shales, etc., tilted at an angle of 45° towards the Birahi Ganga valley. After a period of heavy rain a plane developed on which the overlying mass slipped down 3000 feet; it even rose some distance up the farther slope. It filled the valley for a width of 2 miles and to a height of 850 feet (to the saddle) with about 5000 million tons (0·5 cubic miles) of rock débris; a snowy dust settled on everything for miles around. It took a year for the lake to fill, but when the water overflowed at the saddle 12×10^9 cubic feet of water were discharged, and the 'dam' was cut down 400 feet with extreme rapidity. The flood water rushed down the valley at 20 miles an hour, and at a depth of from 100 to 170 feet far downstream. Perhaps the largest known landslip is that called the Saidmarreh of Luristan, Persia, which occurred in prehistoric times. The scar shows for 9 miles, indicating a mass 1500 feet high and 2·5 miles wide. The material buried the confluence of the Saidmarreh and Kashgan rivers to a depth of 1000 feet. The gorge breached by the impounded waters is still 400 feet deep, and the débris can be traced over 64 square miles. The mass was estimated at over 4 cubic miles.

VOLCANIC EXPLOSIONS

The volcanic dust from the violent eruption of Vesuvius in A.D. 79 buried the Roman cities of Pompeii, Stabiae, and Herculaneum so completely that their sites were lost for centuries. More recent, and far more violent, was the explosion of 1883 which blew the island of Krakatoa out of the sea. The island was estimated at 3 miles by 5, and rose to 2500 feet above sea level, while the cavity after the explosion was 1000 feet below sea level. The volume of lava, pumice, and dust blown up is estimated at over 5 cubic miles. The volcanic dust attained a height of 90,000 feet, the sea waves on the adjacent coast repeatedly surged to 80 and 100 feet, the dust caused darkness within a radius of 25 miles, and two weeks after the explosion the pumice floating in Lampong Bay, 50 miles to the north, was 14 feet thick. A similar event occurred in 1912, in Alaska, when Mount Katmai exploded and left a crater 3 miles across and 3700 feet deep. Kodiak Island, 100 miles away, received a coat of dust more than a foot deep. The Valley of Ten Thousand Smokes, which came into existence at that time, is now included in the Katmai National Memorial. It is estimated that the material blown out as pumice and dust must be regarded as about 5 cubic miles.

EROSION BY RIVERS

The work of rain and rivers is usually done quietly and gradually, but it requires heavy rain and floods to sweep away the decomposed rock or detrital material. Figure 1 shows a Baluch defile, near Mach, which was rapidly cut by the tremendous floods which follow any heavy rain in this arid region. The 'secret of the chasm' is the large boulder seen in the floor. It is lifted and rotated by the eddy that develops at this point, and becomes a veritable boring machine which drills into the bed and deepens the defile during each period of flood. Another example of stream-bed movement was discovered in the Black Canyon, when the Hoover (Boulder) Dam was built. Under 40 feet of sand a piece of sawn timber was found resting on the main rock floor, and an inner deep canyon was discovered extending 70 feet below. The scoured condition of the rock walls of the inner canyon, together with the evidence of the timber, showed that the entire mass of sand which covered the floor of the Black Canyon must have been in turbulent movement through the gorge whenever the Colorado River came through in high flood. Since the various dams have been built and the reservoirs above each have become silt traps—Lake Mead above the Hoover Dam and Lake Havashu above the Parker Dam, etc.—it is noticeable that the river is now re-excavating silt it had previously deposited as bed load. This erosion is taking place below the dams, as the river does not now replenish the deposits which the floods bore downstream.

The erosion from a large drainage area, the Mississippi ($1{\cdot}25 \times 10^6$ square miles), with its eastern humid region and arid western plains, amounts annually to 80 tons of dissolved matter, 288 tons of suspended silt, and 32 tons of bed load from each square mile; it is carried into the Gulf of Mexico. In the case of the Nile, which draws its floods and silt almost entirely from the erosion of the Abyssinian highlands during the rains, the annual totals are 57×10^6 tons of fine silt and 20×10^6 tons of soluble matter from half the total catchment of $1{\cdot}5 \times 10^6$ square miles, at Aswan. The Nile floor is under erosion from Khartoum to Aswan, and re-excavation of older alluvium is in progress between Aswan and Cairo. This river-bed erosion is thought to be due to rejuvenation by a steepening of the river gradient, as a result of the weight of the deltaic alluvium on the one hand, and unloading (by erosion) in the region to the south-east and south of Aswan on the other. If an assumption of 300 tons of material removed per square mile per year is accepted for the land surface of the earth ($57{\cdot}5 \times 10^6$ square miles)—allowing 210 tons for suspended matter, 60 tons for dissolved material, and 30 tons for bed load—the annual erosion will amount to 2·177 cubic miles (1·531, 0·431, and 0·215 cubic miles respectively for the silt, solubles, and bed load). The amount of land above sea level is estimated at an average elevation of 2500 feet, say 0·5 mile, therefore the volume will be $28{\cdot}75 \times 10^6$ cubic miles. With erosion at the rate of 2·177 cubic miles annually the entire land area of the earth would be reduced to a base level in less than 14×10^6 years.

CONCLUDING REMARKS

As considerable areas of the land surface are not under active erosion—deltas, deserts, lakes and regions of inland drainage, and the polar regions under thick ice sheets—it is certain that the rate of erosion assumed in the previous paragraph is too high; but at even a quarter of the rate of 2·177 cubic miles, the continental regions would, theoretically, be worn down to sea level within 60×10^6 years (since the beginning of the Eocene period). Although erosion (and sedimentation) began on the earth's surface in a Pre-Cambrian era perhaps 15×10^8 years ago, it is safe to say that 5×10^8 years have elapsed since the earliest fossiliferous strata were laid down in a Cambrian sea covering part of Wales. The total thickness of strata laid down, in one part of the world or another, during the successive geological eras—Lower and Upper Palaeozoic, Mesozoic, and Kainozoic—may, if put as in a single vertical column, amount to 60 miles (316,800 feet). They were not, however, deposited to this amount, or to even a quarter that thickness, in any one region, nor were they all deposited in the sea. If they represented the volume of the present land mass, in the form of silt (1·746 cubic miles annually), a pile of that height would cover less than 480,000 square miles of the earth's surface. We must recognize then that, even at the slowest rate of erosion, the materials of the earth's land mass could have been eroded over and over again at least eight or nine times. There is thus evidence, irrespective of the data obtained by seismologists, that erosion and sedimentation upset the balance of loading on the earth's shell, and that, in consequence, the outer crust bends and buckles. Indeed, these adjustments take place rapidly, and the crustal movements must, in the course of time, lead to folding and faulting and such crumpling and kneading that sedimentary rocks may be forced deep into the crust in some places, and elevated in other cases. Thus we find Permian strata forming the mass of Everest, but may not recognize the dust of Krakatoa as the fused débris of perhaps an Eocene clay, and some granites may be the recrystallized form of sediments which were forced down to the base of the Sial layer at the Mohorovičic discontinuity.

Ecology of ciliate infusoria

E. FAURÉ-FREMIET

Ciliate infusoria are in general highly resistant to physical changes in their environment, and research indicates that their development is largely determined by the amount of food available. Many of them have developed ingenious and highly specialized mechanisms for capturing and ingesting their food. Their ability to assume a number of different forms at different stages in their life-cycle has often caused confusion and led to the classification of more species than do in fact exist, as Professor Fauré-Fremiet here explains.

Among the protozoa the ciliate infusoria show a very high degree of differentiation and morphological complexity. Almost 120 years ago Ehrenberg described them as organisms in the fullest sense of the word; he erred only when, comparing the structure of these organisms with the smaller metazoa such as the rotifers, he thought it possible to superpose real structural homologies on functional analogies. It needed at first all the knowledge of F. Dujardin to realize that the ciliates, like the rhizopods, are formed of viscous matter, and that therefore they constitute a new kind of structural organization. It then needed the generalizing mind of V. Siebold to identify the sarcode of Dujardin with the protoplasm of H. Mohl, and to regard the protozoa as unicellular organisms. Finally, it needed the critical observations of C. C. Dobell to recognize that the protozoa can be described with greater exactitude as noncellular organisms.

Owing to the wide range of form, the ciliates can adapt themselves to an equally wide range of habitat. Although it is easy to distinguish planktonic and littoral forms, motile and sedentary species, and those whose feeding habits, though generally phagotrophic, are more precisely described as microphagous or macrophagous or histiophagous, etc., much remains to be learnt about the ecology of these organisms.

In this respect the small size and rapid rate of multiplication of the ciliates allow their populations and their partnerships to develop both in a restricted space and in a short time. This circumstance is very favourable to the study of the interrelationships and interdependencies which are established, not only between the different species of infusoria, but also between them and other organisms of small size, both animal and plant, the whole assemblage forming what we may call a microbiocenosis.

The ciliates are widespread in all aquatic habitats; among other investigations, those of L. Noland, Wang, and Picken show that their margin of tolerance is fairly high in regard to various physico-chemical factors such as light, temperature, *p*H, salinity, and content of oxygen and carbon dioxide in the water.

It seems therefore that food supply is the chief factor influencing the community and its eventual location within certain limited biotopes. Unfortunately our knowledge of the alimentary physiology of ciliates too often remains uncertain, and the following example will show the ecological significance of this fact. The *Ophryoglenidae* are holotrichous ciliates frequently met with in fresh and salt water, but almost always as rare and scattered individuals whose precise identification is difficult from the descriptions given by earlier workers. Research done in my laboratory by Hélène Mugard shows that the *Ophryoglenidae* have a peculiar physiological cycle which had not previously been suspected. These infusoria are sometimes found in clear water in the form of long and transparent individuals, swimming at great speed, which one is tempted to regard as essentially plankton; in fact they are hunters or beasts of prey. If one of them happens by chance to come near to a wounded organism or to animal débris, a chemotactic stimulus is set up, due to some diffusible organic compound which attracts it towards the wounded tissues; its shape changes suddenly, then it attacks the tissues with a gimlet-like movement, worms itself between the cells and greedily ingests the débris. The satisfied infusorian, now thick and opaque, has become unrecognizable and appears to be another species; it moves slowly away from its feeding place, encysts below the surface, digests its meal, and divides two or three times, forming four or eight swimming organisms similar to the parent, which are soon in quest of food. Such histiophagous ciliates remained for long unrecognized. Observations of their life-cycle *in vitro* were needed in order to define the species and to grasp the eventual importance of the part they played in the economy of small aquatic communities.

The microphagous ciliates are by far the most frequent and the richest in variety of species. They feed on minute organic particles and bacteria in suspension, which are drawn towards their mouths by means of a current set up by the movement of their cilia. Other species are macrophagous; some are herbivorous, feeding on diatoms, desmids, *Oscillatoria*, etc.; others are carnivorous, feeding on other infusoria. Some of these can tackle large prey, which is often stunned by a discharge of toxic trichocysts before being swallowed; microcinematograph records made by J. Dragesco vividly demonstrate their voracity.

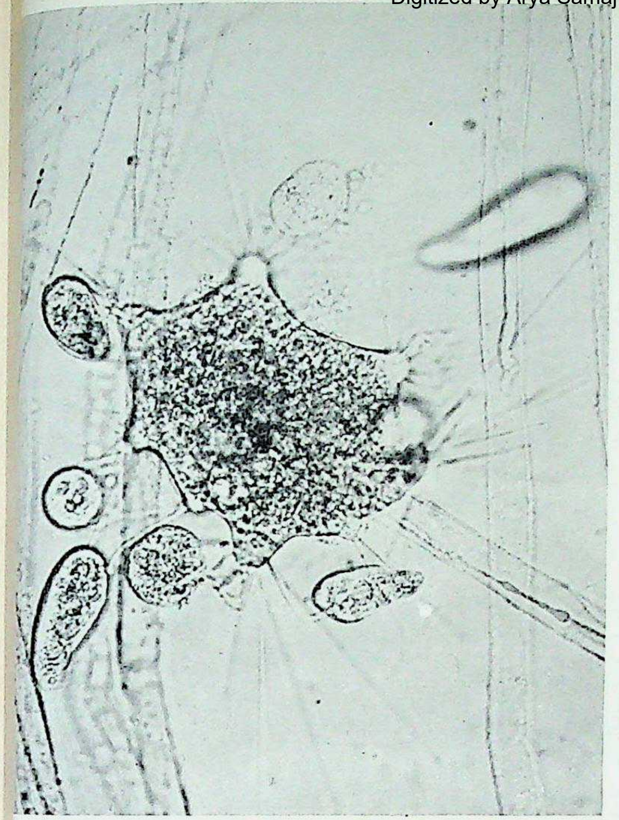
It is important to note here that, for a large number of ciliates, both microphagous and predatory, the feeding is selective, and that certain prey, whose specificity can be narrowly determined, is essential for the sustenance of a given species. This fact may be associated with some structural peculiarity influencing capture and ingestion, but it can more often be linked with a biochemical peculiarity.

The elegant researches carried out in the laboratories of A. Lwoff and of G. W. Kidder on the nutrition of ciliates maintained in sterile culture show, in fact, that many of them have only a restricted power of synthesis. Their maintenance requires the supply of complementary substances, or growth-factors, elaborated either by bacteria, or perhaps by algae, or even by other ciliates. It thus appears that the essential food substances can create conditions of nutritive interdependence, more or less narrowly specific. Such interrelations are generally the beginning of all microbiocenoses.

Different types of associations of which the principal members are protozoans and protophytes are formed in fresh water. A relatively simple case is the *Beggiatoa* association. The colourless sulphur bacteria, *Leucothiobacteriales*, often grow as white, velvet-like patches on black mud rich in organic matter and covered by a shallow depth of running water. Their presence shows the pre-existence in the mud of anaerobic bacteria capable of decomposing the organic matter and forming the hydrogen sulphide which *Beggiatoa* uses in respiration. The white patches thus develop as the result of a bacterial association. Their appearance depends on the properties peculiar to the sulphur bacteria, whose long filaments move slowly on the surface of the mud, becoming entangled and forming a felted mat, the contour and thickness of which are regulated by a twofold tendency—surface spread and superficial condensation. The colony of *Beggiatoa* holds water, which is slowly renewed; testing with phenol red at the edge of the colony gives a yellow tint, indicating a *p*H slightly more acid (about 6·8) than that of the aqueous medium. This acidity, due to the metabolism of *Beggiatoa*, produces a chemotactical swarming of two common species of microphagous ciliates, *Colpidium campylum*, and *C. colpoda*, which collect round the colony, penetrate it, and feed actively upon the small bacteria composing it. From that moment two ecological effects begin to operate—the formation of a food chain and the initiation of the microbiocenosis. The reproduction of these two species of *Colpidium* in this favourable habitat leads to a great density of population; it must be noted that this density is a result not only of multiplication, but also of the statistical equilibrium between the entrances and the exits of the motile organisms which stay a longer or shorter time in the felt of bacterial filaments in which they find their food. The two species of *Colpidium* do not disturb each other. Nor does their presence seem to harm *Beggiatoa*—rather the contrary, because the movements of the infusoria ensure renewal of water inside the colony and preserve its shape and activity.

The balance of the association is soon modified by new arrivals belonging to the class of predatory infusoria. These voracious ciliates are usually represented only by widely scattered individuals. Some feed almost exclusively on *Colpidium campylum*; such are *Enchelys mutans*, *Lionotus lamella*, and *Leucophrys patula*. If one of these ciliates enters the neighbourhood of the *Beggiatoa* community it begins to feed on its usual prey, and its rate of reproduction is sufficient to ensure an almost complete destruction of the *C. campylum*.

These three predatory species are apparently equivalent and interchangeable if one considers only the effect exercised by one or another on the equilibrium of the original association, but if two of them arrive simultaneously it is no longer so. The experiments carried out by J. Ducornet show, for example, that *Lionotus lamella* is capable of attacking *Leucophrys patula*, and that the *Leucophrys* can swallow small specimens of *Lionotus;* in this case, the prey ingested devours and kills its attacker, so that the contest is generally fatal to the *Leucophrys*. The destruction of *Colpidium campylum* limits the increase of *Lionotus* automatically, by lack of food, and seems to retard indirectly that of *Colpidium colpoda*.



GURE I – Trichophrya epistylidis *on peduncles of* rchesium, *capturing and sucking* Colpidium cam-
lum.

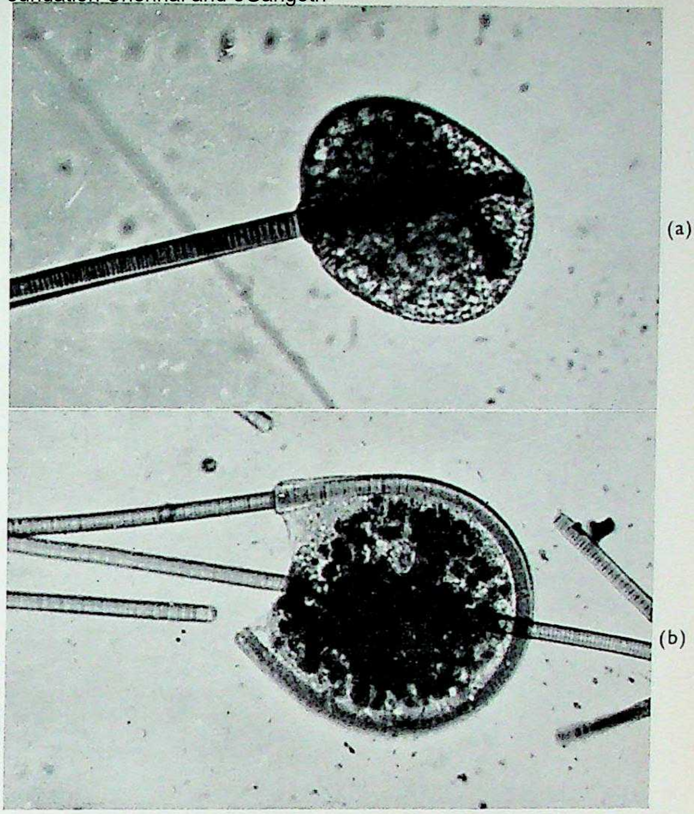
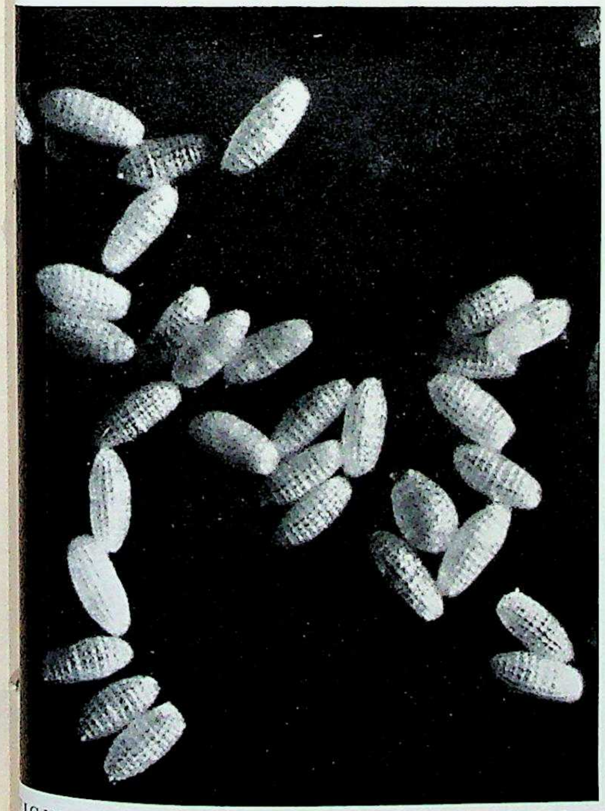


FIGURE 2 – Nassula ornata *ingesting* Oscillatoria. (a) *Beginning of ingestion.* (b) *The body of the infusorian is deformed by the elasticity of the trichome.*



IGURE 3 – Coleps hirtus *seen in refracted light, after* *ncineration, to show the calcified skeleton.*

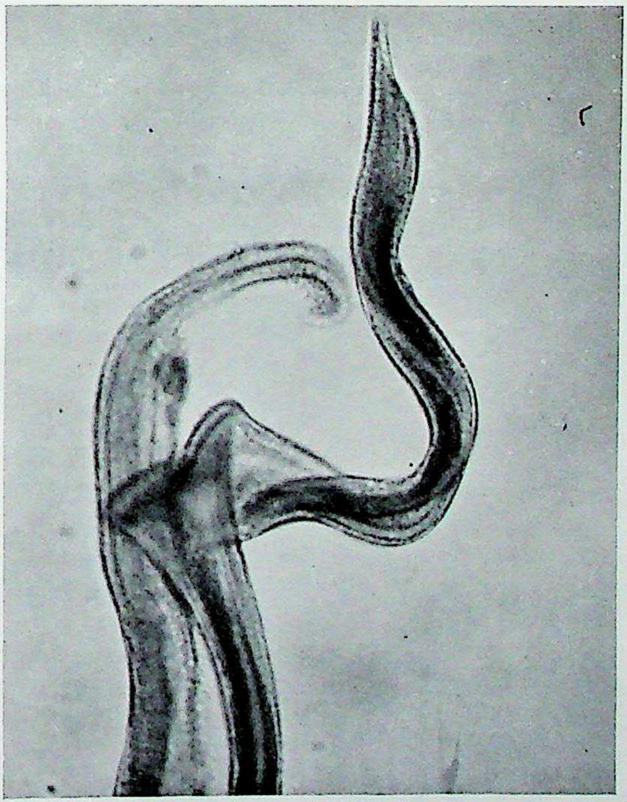


FIGURE 4 – Centrophorella fistulosa, *a very large ribbon-like infusorian, characteristic of fine marine sands.*

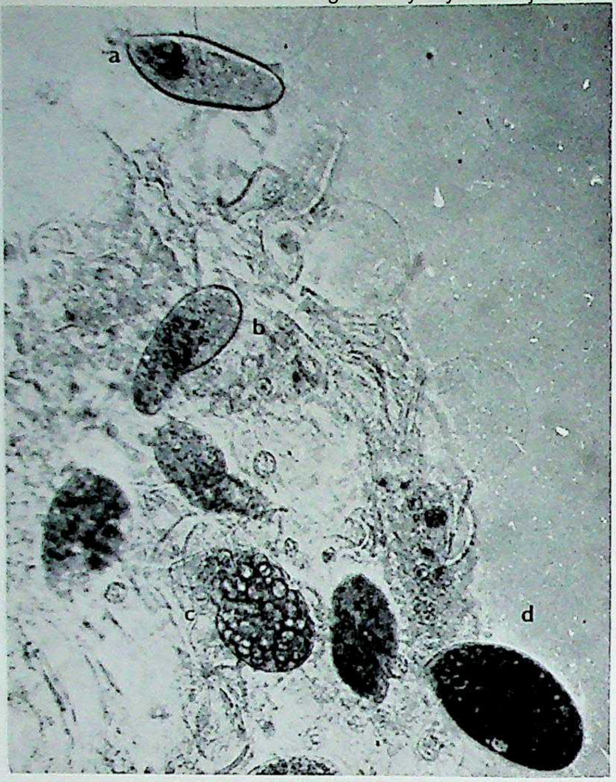


FIGURE 5 – *An Ophryoglenid.* Deltopylum rhabdoides *attacking the intestinal tissue of a larva of Chironomus.* (a) *A predatory individual coming into contact with the tissue.* (b–d) *Individuals ingesting tissues, seen in different stages of repletion.*

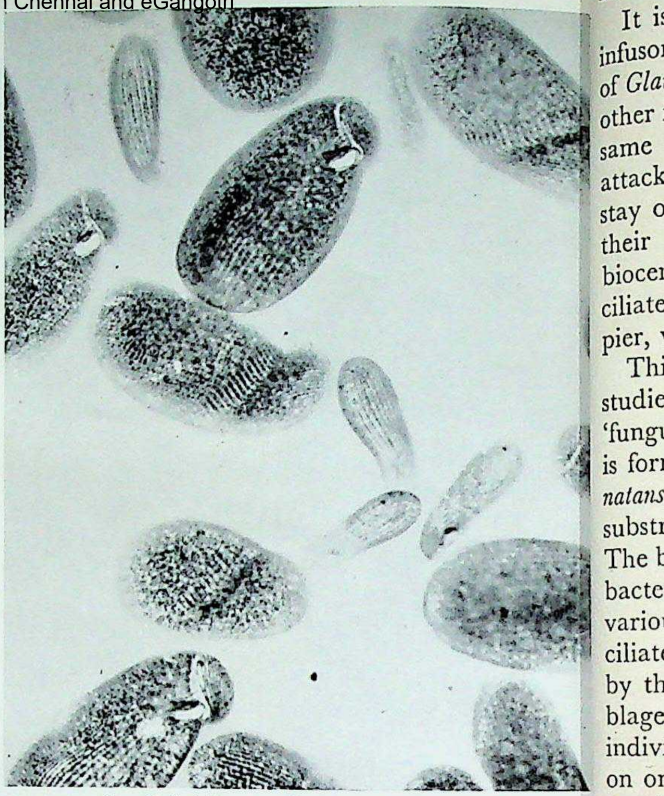


FIGURE 6 – Colpidium colpoda *and* C. campylum. *stained with silver by the method of Chatton and Lwoff.*

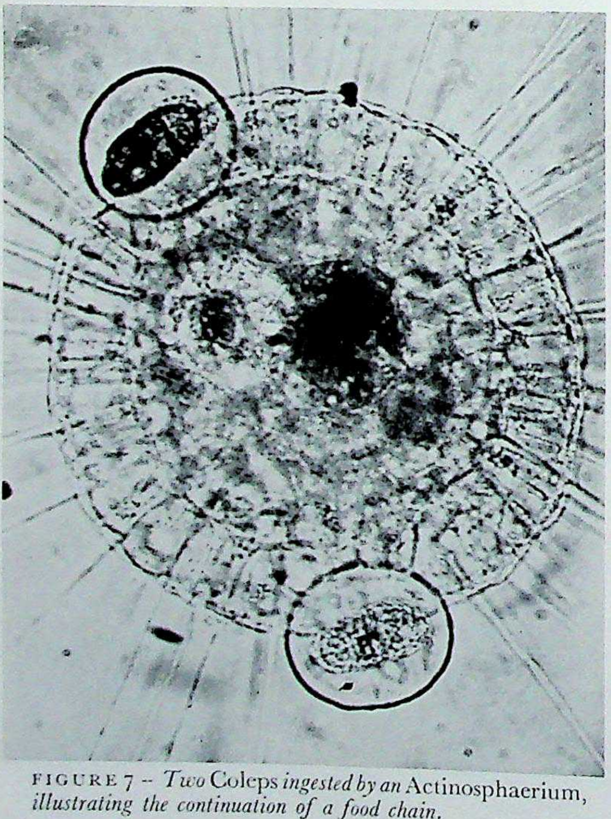


FIGURE 7 – *Two* Coleps *ingested by an* Actinosphaerium, *illustrating the continuation of a food chain.*

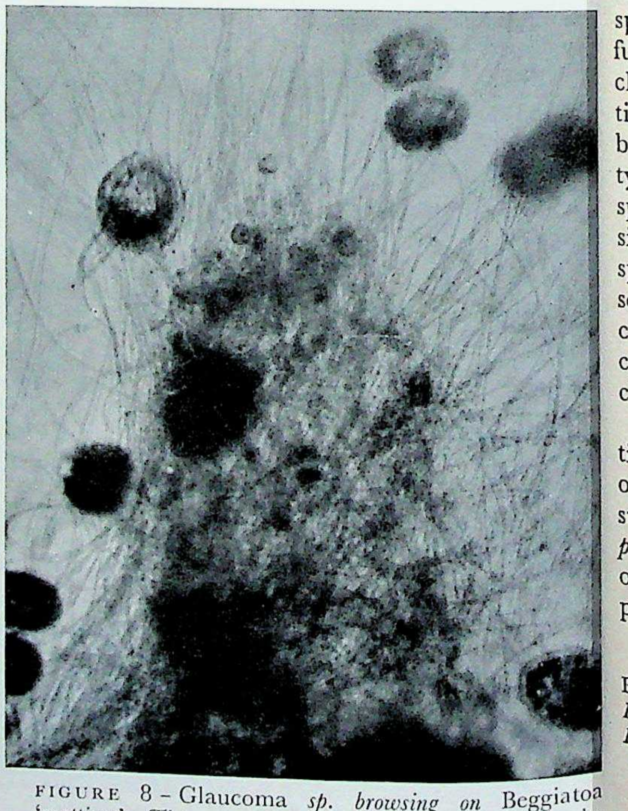


FIGURE 8 – Glaucoma *sp. browsing on* Beggiatoa *'matting.' The accumulation of refringent sulphur grains stains the filaments deeply.*

It is then that two new species filter into the infusorian colony, already sparse. One is a species of *Glaucoma* which feeds entirely on *Beggiatoa*; the other is *Chilodonella cucullus*, which uses mainly the same sulphur bacteria. These two species thus attack the organic matting which was the mainstay of the association, and, with its destruction, their rapid increase produces the end of the biocenosis, the remains of which are ingested by a ciliate detritus feeder, *Coleps hirtus*, the last occupier, which increases in its turn.

This is not an isolated example. Picken has studied two other types of microbiocenosis, the 'fungus association' in which the organic substrate is formed by the mycelial network of *Sphaerotilus natans*, and the blue-green association of which the substrate is formed by the filaments of *Cyanophyceae*. The basic nourishment, formed in the first case by bacteria and in the second by diatoms, is used by various species of protozoa and, more especially, ciliates which begin various food chains continued by the predatory carnivores. Hence 'the assemblage of protozoa . . . is not a collection of individuals depending directly, for the most part, on one source of food, but a differentiated community of herbivores and carnivores forming, with the basic food supply, a closed social unit.' This conclusion is equally valid for *Beggiatoa*. In each of these biocenoses each of the associated species plays (as Picken suggests) a definite role, or fulfils, one might say, a particular function, the character of which depends on its specific nutritional needs and whose relative importance is bound up with its ability to reproduce. For each type of community the functional distribution of species attains a characteristic social structure. A similar role can, however, be played by several species, which are equivalent and interchangeable, so that the specific composition of an association can vary without modifying the social structure, comparable with the convergence of the food chains in a pyramidal form as described by Elton.

Parallel with their social structure, the associations have a physical structure the characteristics of which depend on the nature of the organic substrate: fungus mycelium, filaments of *Cyanophyceae*, or, in the preceding case, the felted mat of *Beggiatoa*. Picken stresses the important role played by this reticulate structure, which allows the movement in response to contact-stimuli so common among the protista, and which holds within its mesh a body of liquid forming, so to speak, the inner core of the biocenosis.

The large sedentary infusoria such as *Stentor*, like the branching colonies of *Carchesium*, *Epistylis* and *Opercularia* developed on submerged surfaces, can form a useful organic substratum for certain associations. The strong currents of water set up by the ciliary movements of the zooids drive to the bottom a large number of particles, bacteria, and diatoms. These soon cover the substratum and are used by the various motile ciliates, microphagous or herbivorous, which form the floating population. These in turn are exploited by tentaculate protozoa, the messmates of the colonial vorticellas, or by various special predators, some of which even attack the colonial zooids themselves.

The associations of planktonic ciliates are no less interesting than the littoral biocenoses. In them, also, systems of convergent food chains can be established, but the physical structure of these diffuse associations can almost be compared to that of a solution. The sand-dwelling infusoria (E. Fauré-Fremiet, 1950), and their trophic association with the flagellates and the bacteria, show a similar case in a very different medium; the damp sand of marine beaches, for example, acts as a solvent habitat. The mesopsammon (community between the sand grains) can be compared, in fact, to a solid plankton.

If the ecology of the ciliates is clearly dominated by their food requirements, it must not be forgotten that the astonishing plasticity of these acellular organisms has made it possible for them to assume very varied specific forms, closely suited to the conditions of the habitat. While not stressing this other aspect of the ecological problems, it can be noted that the diluted associations such as plankton, or the sand-dwelling types, are often characterized by species which are morphologically specialized. On the other hand, the littoral associations described previously, which may by contrast be called coacervations (massed communities), appear, in the course of their evolution, as biological units of a higher order, among which one can recognize, with Picken, a certain degree of physiological integration.

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The technique of biological staining

H. GRAHAM CANNON

The importance of staining in studying the fine structure of living organisms is difficult to overestimate. Many structural details of the greatest significance are invisible in the natural material but can be revealed by the skilful use of selective dyes. Research in staining has also resulted in new means of analysing the physiology of cells as well as their anatomy. The accompanying illustrations show some of the striking results which can be obtained.

In the Sheffield (England) Art Gallery and Museum there is exhibited a collection of remarkable lantern slides of marine animals. These are not, as might be expected, pictures or photographs but the actual animals flattened and mounted in Canada balsam. They were made by Dr W. C. Sorby about the middle of the nineteenth century, and will serve as an introduction to this short article on the technique of staining as applied to the study of the microscopical anatomy of both animals and plants. Some of Sorby's specimens retain their natural colour to a large degree. For instance, a small plaice shows all the pattern of its natural pigmentation, but others, such as *Aurelia*, the common jellyfish, are stained, and the stains that Sorby employed are quite entertaining. He used carmine, which is now one of the standard stains used in all elementary classes, but in addition he experimented to a considerable degree of success with all sorts of extracts. He used damson juice and bilberry juice, and one of his most successful stains was port wine. I should think from the colour of the specimens that he used a good tawny port rather than a more mature vintage type. As far as I could ascertain, he did not use the now famous extract of the bark of the logwood tree known to us as haematoxylin. This was first used in 1863, and his specimens are probably of an earlier date.

The scientist who is not a biologist might reasonably ask why Sorby should have taken the trouble to stain his specimens: we can see living animals and so, surely, we can see them when they are preserved. This is not strictly correct, for many animals are almost impossible to see when alive. Living protoplasm, in fact, in its pure state is colourless and transparent. This can be illustrated in a striking manner if a sample of microscopic floating life or plankton is collected, say in Windermere. In the summer there will nearly always be present a water-flea called *Leptodora*. This form, as a water-flea, is comparatively enormous, for it is half an inch long, yet it can be seen among the other floating life only by the fact that as it swims about it knocks all the other tiny water-fleas out of the way. It is glassy transparent with only one black pigment spot, which is its eye. In order therefore to see its shape and size, we must pickle or 'fix' it. The aim of this fixation is to precipitate the colloidal living matter in as lifelike a condition as possible. Naturally, with the development of microscopical technique there have been discovered a large number of fixatives, all of which have their own good or bad qualities. On fixing a living *Leptodora*—no matter what fixative is used—the body changes from glassy transparency to opaque white. We have, in fact, by the process of fixation merely converted something which was so transparent that we could not easily see its external shape, into a form which is so opaque that we cannot see through it and therefore cannot study its internal anatomy. This opacity can be overcome by removing the water from the specimen and then replacing it by an alcohol, such as ethyl alcohol, and subsequently by some highly refractive oil like oil of cloves or xylol. The specimen then regains its complete transparency. The only parts of it that will be visible are those which contain pigment, or more accurately, those which have retained their original pigmentation through this drastic process of water removal, for during fixation and subsequent treatment many substances in the cells are either broken down or dissolved away.

Unstained specimens mounted as I have described are permanent. They can be mounted in Canada balsam, and there is then no reason to suppose that they will not last for all time—a great point in their favour. Also, it is possible, though difficult, to use them without further treatment for anatomical study. It is only if, by the remotest chance, the refractive index of their substances were

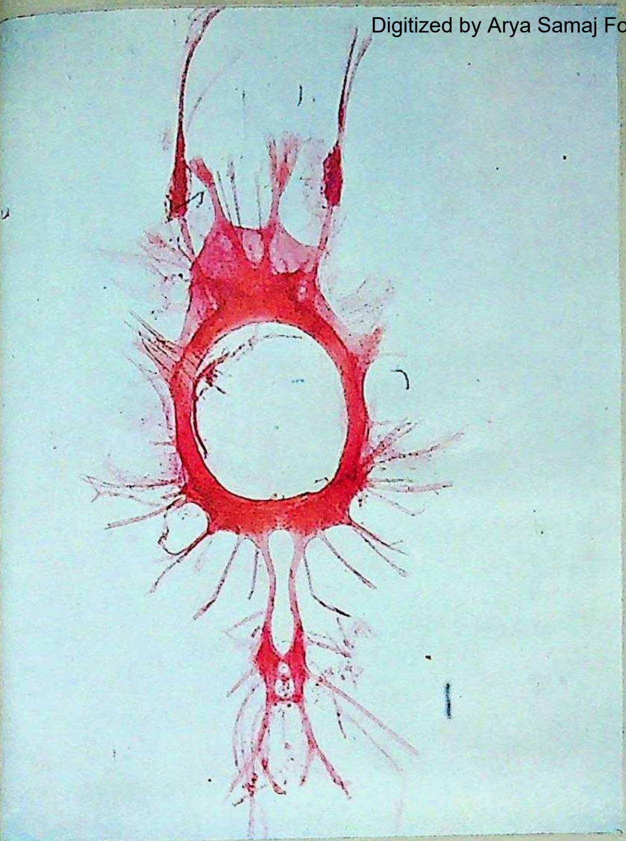

FIGURE 1 – *A general stain. Nervous system of an Ostracod dissected out and stained in Borax Carmine.*

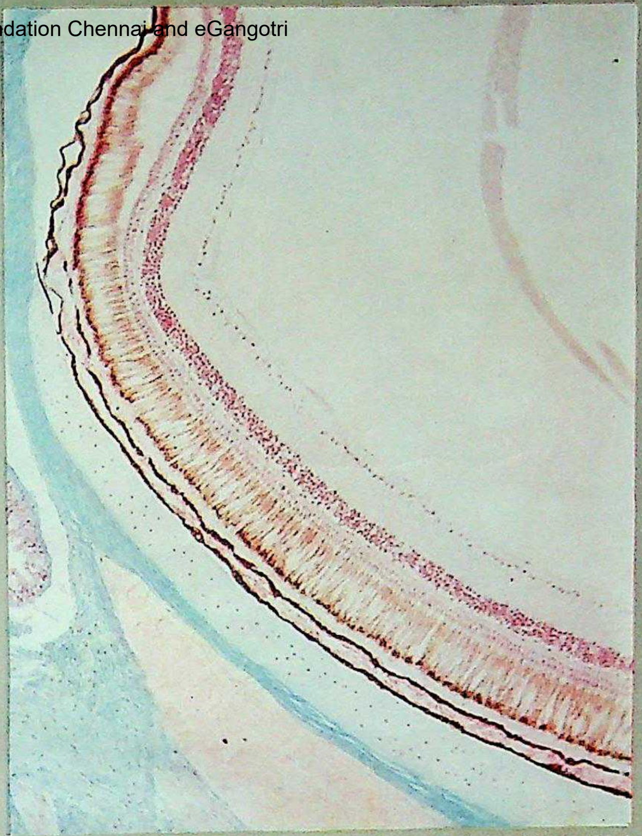

FIGURE 2 – *A triple stain. Section of mammalian retina stained in the orthodox Mallory stain. Cartilage and connective tissue stain blue, blood cells red, and the nuclei of the retinal cells purple.*

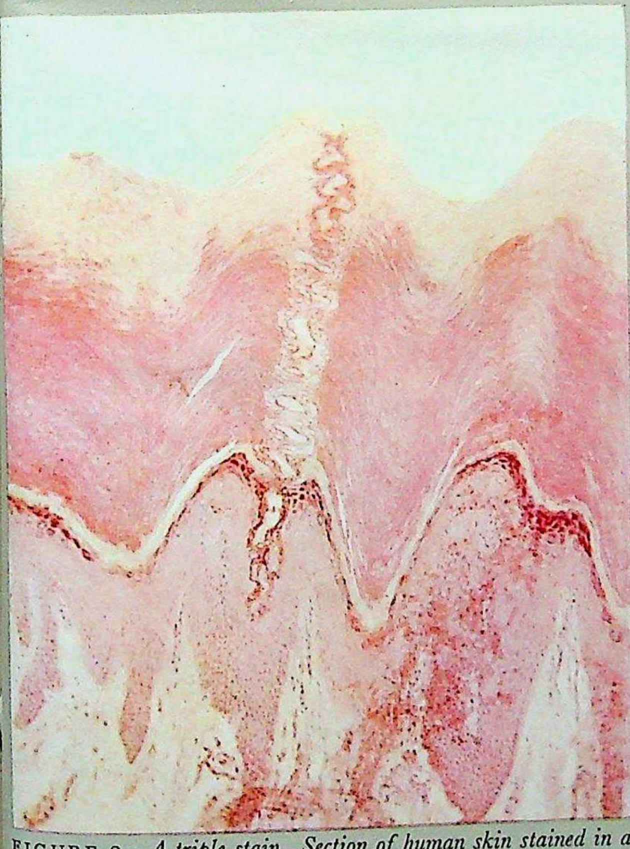

FIGURE 3 – *A triple stain. Section of human skin stained in a modified van Gieson stain. This demonstrates that the outer layer,* the stratum corneum, *is chemically two layers, the outer staining with picric acid and the inner with fuchsin. Inside this are the* stratum lucidum (*picric acid*), *and then the* stratum granulosum

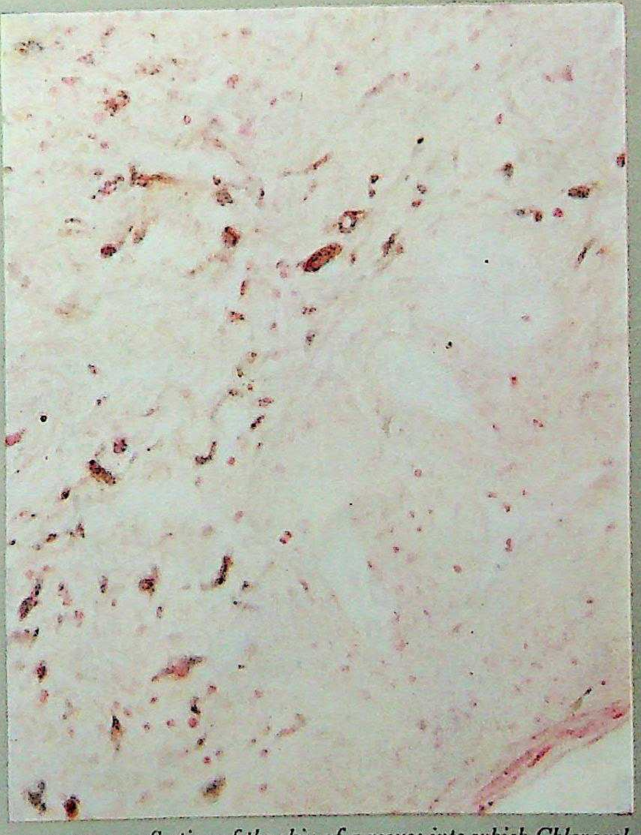

FIGURE 4 – *Section of the skin of a mouse into which Chlorazol Black E had been injected. The histiocytes which have taken up the dye show black against the rest of the section, which has been stained with an orange for the cytoplasm and a red for the nuclei.*

(By courtesy of Dr J. R. Baker, Oxford)

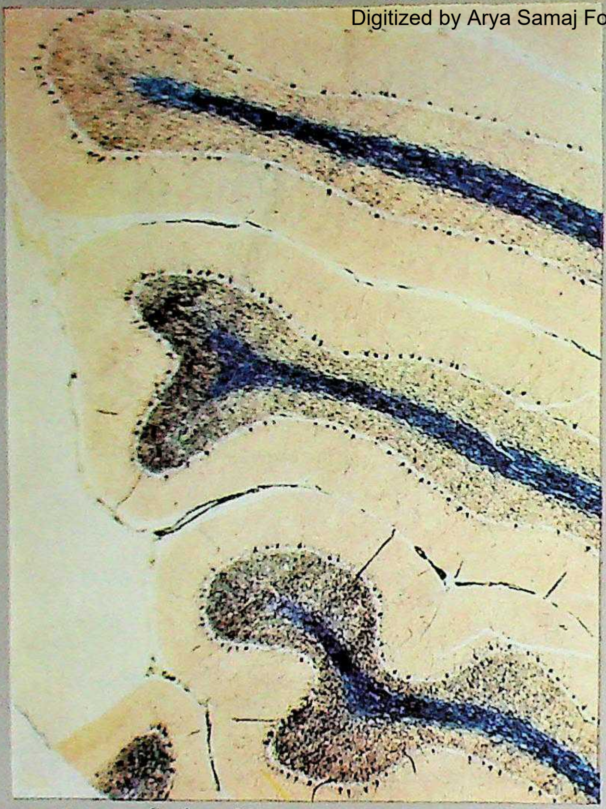

FIGURE 5 – *Section of mammalian cerebellum. Impregnation by silver subsequently treated by gold.*

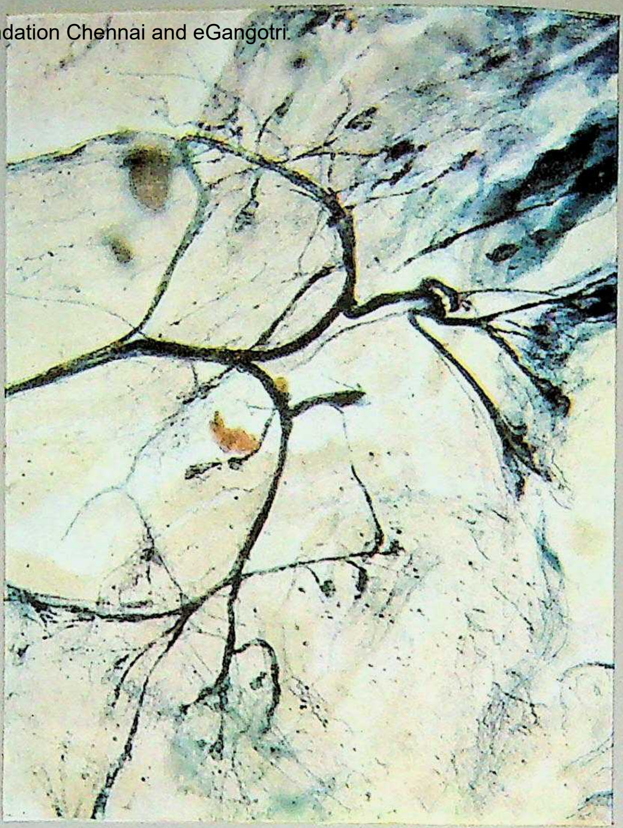

FIGURE 6 – *Impregnation by gold chloride of nerve endings on skeletal muscle.*

FIGUR
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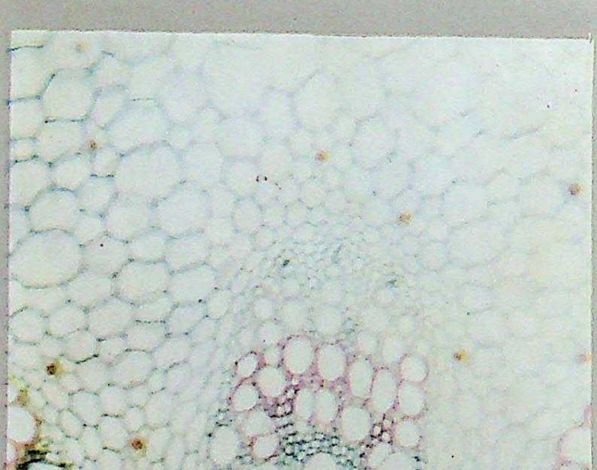

FIGURE 7 – *A double stain. Transverse section of the stem of* Helianthus, *showing lignified cells staining pink with Lignin Pink and the rest of the tissues with Chlorazol Black E.*

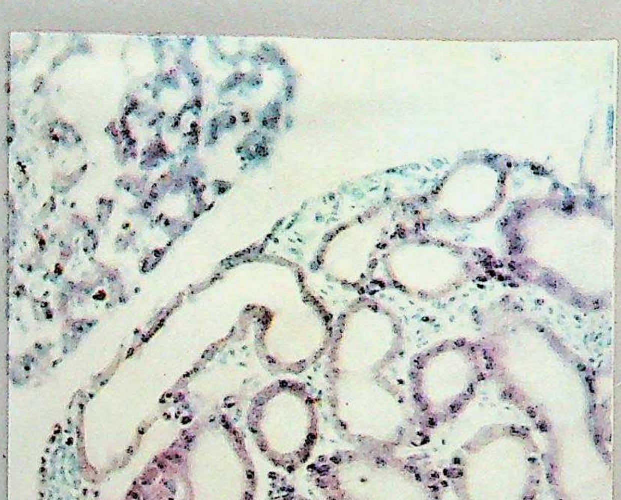

FIGURE 8 – *A double stain. Section of kidney of frog tadpole, showing red blood cells coloured green with Victoria Green and the rest of the tissues purple with Hickson Purple.*

FIGURI
Black E

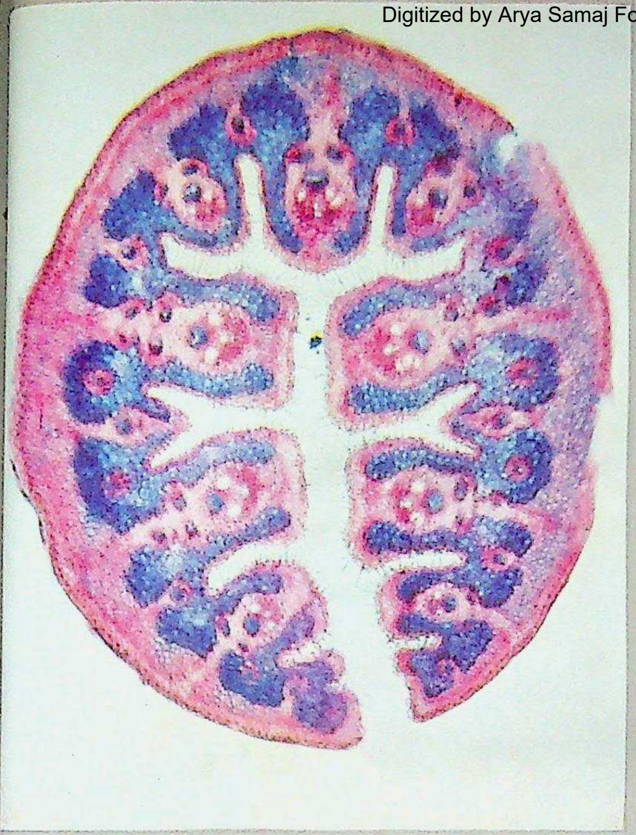

FIGURE 9 – *A single stain producing multiple effect. Transverse section of dried esparto grass stained with Chlorazol Azurine.*

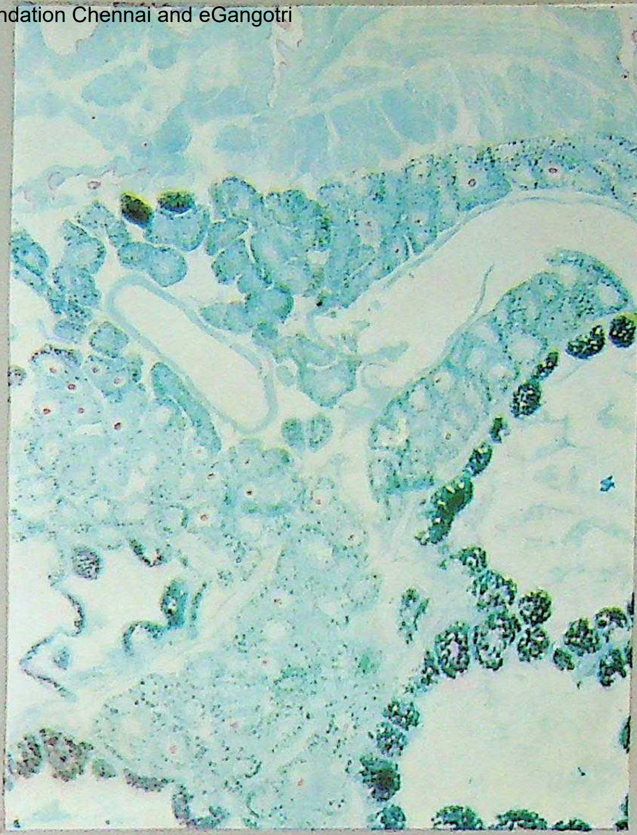

FIGURE 10 – *Staining effect produced by fixation. Fat droplets stained black by osmic acid fixation and the rest of the section double-stained light green and red.*

(*By courtesy of Professor R. Dennell.*)

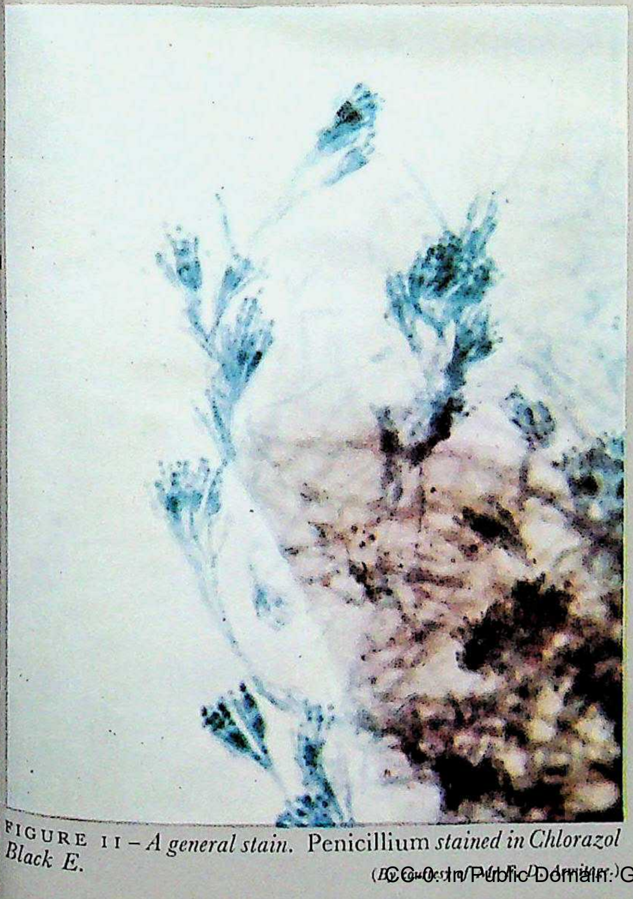

FIGURE 11 – *A general stain.* Penicillium *stained in Chlorazol Black E.*

(*By courtesy of Mr. F. D. Armitage.*)

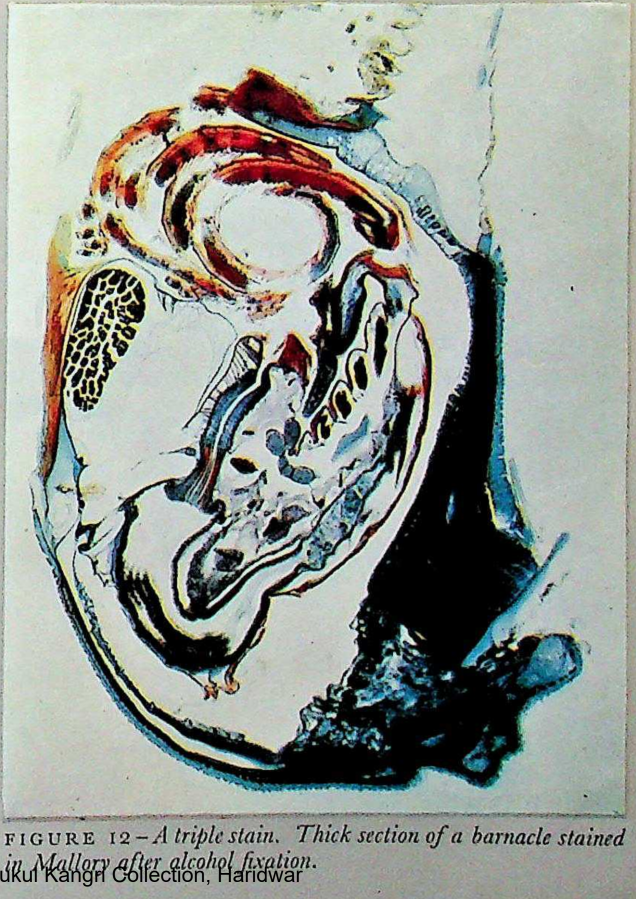

FIGURE 12 – *A triple stain. Thick section of a barnacle stained in Mallory after alcohol fixation.*

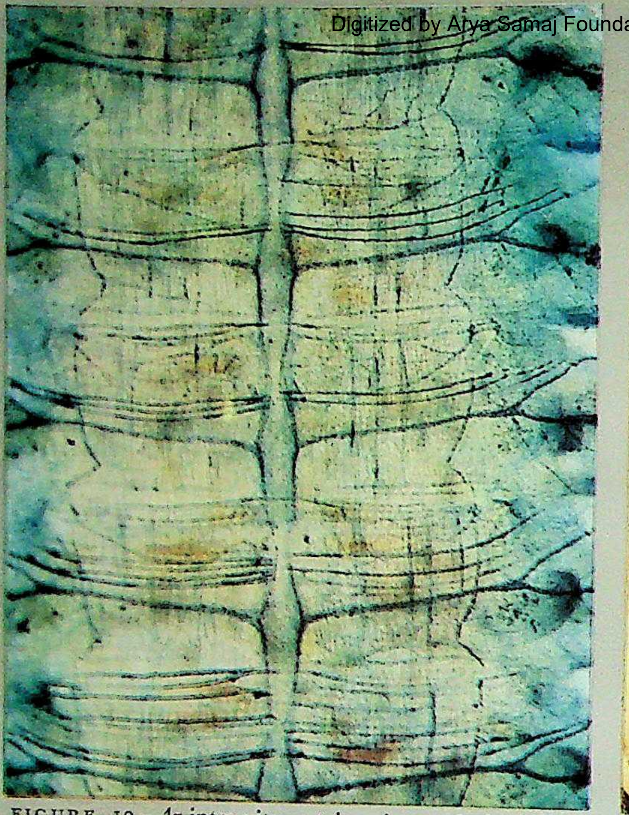

FIGURE 13 – *An* intra vitam *stain, subsequently fixed. Nerve cord of marine worm fixed in I.C.I. zinc-free 'A' methylene blue.*

(By courtesy of Dr J. E. Smith, Cambridge.)

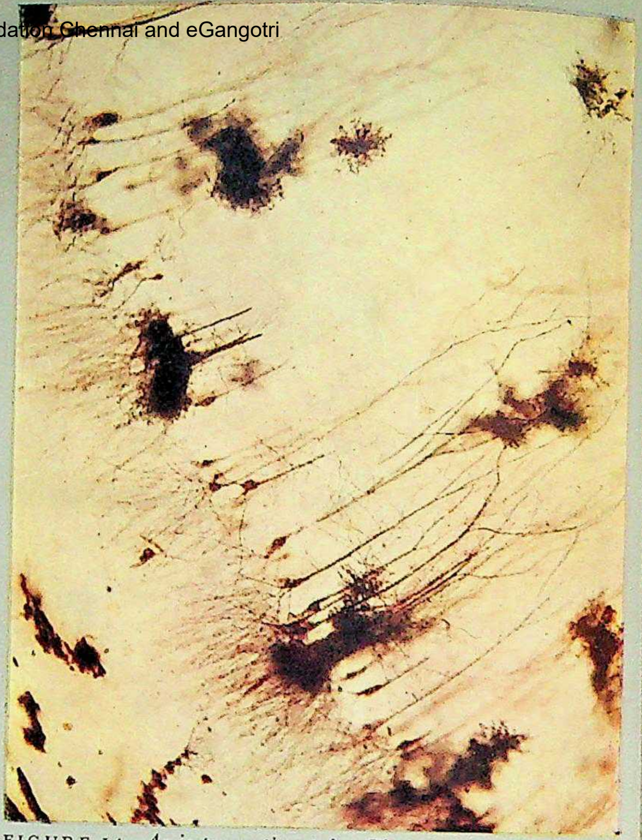

FIGURE 14 – *An impregnation stain. Transverse section of mammalian brain impregnated by Golgi method.*

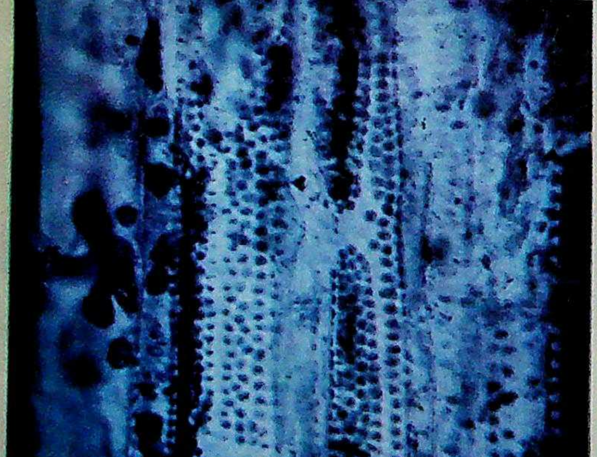

FIGURE 15 – *A stain to show effect of the solvent. Longitudinal section of the stem of* Helianthus *stained in Chlorazol Black E dissolved in benzyl alcohol, showing the pits in the cell walls stained black.*

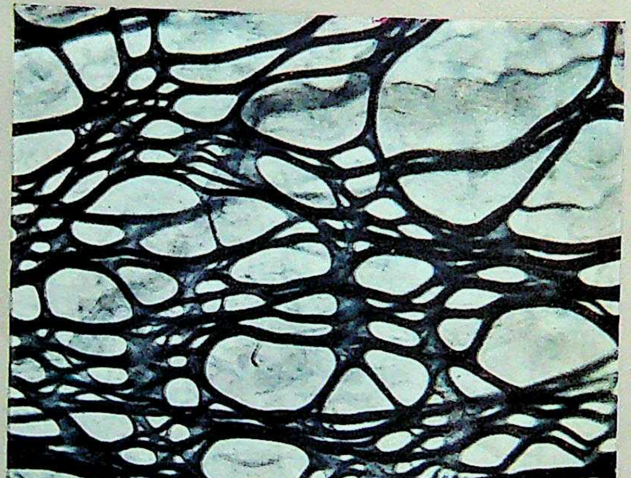

FIGURE 16 – *A selective stain. Body wall of barnacle stained for a very short time in Chlorazol Black E in ethyl alcohol, showing elastic fibres stained purplish-black.*

exactly the same as that of the mounting medium that they would become invisible. In all ordinary cases, however, there is a slight difference of refractive index, and, of course, the slightest difference is sufficient to allow for an image to be obtained by critical illumination. That is indeed the whole point. Good illumination is essential and is possible up to a point, but there are limits beyond which the anatomist cannot go and cannot be expected to go. There are some who have maintained that all microscopical anatomy should be done by means of photographs of unstained preparations, using perhaps ultra-violet light. There is no doubt that such a method has yielded very valuable results in a limited field. For the ordinary micro-anatomist, however, and it is as such that I am writing, a good source of illumination and an optimum use of microscope condensers and objectives are all that can be dealt with. After all, a micro-anatomist is in the habit of looking through series of sections running often into thousands, and it is clear that photographic methods can have only an accessory value. He must have an easy and quick method of seeing his structures, and this is provided by staining the whole specimens or sections before they are mounted in their final medium. When this is done they can be seen easily, but it is by their colour rather than by their refractive index. This was, and largely is, the *raison d'être* of staining. Sorby's jellyfish mounted unstained would have been unrecognizable, so he stained them in port wine and at once their anatomy was easily studied. In exactly the same way today, when I begin a study of the anatomy of some minute crustacean, I cut it into thin slices which I then stain so that I can see them easily under the microscope.

Of recent years the technique of staining has developed tremendously. What started as a simple method of making structures visible has now branched out in all directions, leading to valuable methods of analysis of chemical composition and metabolic activity. *The Quarterly Journal of Microscopical Science* is in fact nowadays largely devoted to the most abstruse biochemistry.

I am, however, concerned with the methods used by an anatomist, and what I want to emphasize is that by far the greater part of the staining carried out by biologists is empirical. It does not matter to the micro-anatomist how or why a particular stain behaves in a particular way, as long as it aids him in his study. What does matter to him is that the stain shall always produce the same effect. In other words, it is constancy rather than purity which counts in a stain. I came across a striking case of this sort after the first world war. A German scientist had described an effect by which the dye alizarin picked out individual nerve fibres in a water-flea. He used a sample of this stain made by Grübler and designated OO: I had some of this particular product and confirmed the experiment, but, when I wanted a further supply, no British alizarin would produce the same effect. In those days, if manufacturing chemists wanted to receive any support from the government they had to produce chemicals as pure as possible. Grübler, on the other hand, saw that as long as he could guarantee to produce the same stain it did not matter to the microscopist using that stain whether it was pure or not, provided that it always produced the same effect. In this case it was clearly an impurity rather than the main chemical which was of value.

In a similar way, Chlorazol Black E was discovered accidentally. It seeped out of a piece of black velvet I was using as a background for the dissection of a small crustacean. Very gradually—in fact after three weeks' intermittent dissecting—it picked out the particular skeletal structures I was endeavouring to see in the unstained specimen, and coloured them a dark green. I therefore boiled a piece of the black velvet in spirit and obtained a black solution which chemists identified for me as Chlorazol Black E. Clearly it did not matter to me why this stain behaved in the way it did. It was a stroke of luck on my part in that I found a solution of very simple use which aided my research.

Subsequently, study has shown that Chlorazol Black E is of very widespread value. Testing it on botanical sections I immediately found that lignified tissue stained the faintest pink. On consultation, a chemical firm produced a pink stain which normally occurs as an impurity in Chlorazol Black E and which is now known as Lignin Pink. Whether the presence of this impurity has anything to do with the general effect of Chlorazol Black E I do not know, but a sample of the latter from which the pink had been removed did not seem so precise in its staining as the ordinary chemical stain.

Again, Dobell, working on entamoebae, showed that the cysts of intestinal amoebae can be identified by staining with Chlorazol Black E. He found that the nuclei and chromatoid bodies stained a sharp black, while the cyst wall stained greyish-green and the glycogen red. Here then is an empirical method of identifying the various types of amoebae which may occur in the human alimentary canal, a method which incidentally can be carried out in an hour, whereas a day at least was necessary by any other method.

Another peculiar but valuable effect produced by Chlorazol Black E is that its staining properties differ with different solvents. Planktonic forms, such as small medusae and the smaller crustacea, stain quite a different colour when the dye is dissolved in ethyl alcohol from that which they show when it is dissolved in benzyl alcohol. More interesting, however, is the effect on plant tissues. In ordinary ethyl alcohol, Chlorazol Black E stains cell walls black, and the other cell structures various colours from yellow through greenish-grey to black. In benzyl alcohol it selectively stains the pits in the cell walls. In a longitudinal section of the stem of the artichoke *Helianthus* the wall of the pitted vessel appears as a sheet of dark grey spots on a colourless background (figure 15). It is difficult to think of an explanation of this difference, but it is nevertheless a very valuable method of investigating plant structure. As a routine method it has been used in the study of the microstructure of wood by Leighton Hare at Kew (England). This worker, as a routine, mounts three sections, one stained with Chlorazol Black E in aqueous solution, another in ethyl alcohol solution, and the third in benzyl alcohol.

The preparations I have chosen to illustrate this article were made by the ordinary routine types of method employed by the micro-anatomist. The first (figure 1) represents a general stain, and shows the nervous system of a deep-sea crustacean dissected from the body and stained with one of the commonest of all stains, borax carmine. For a general stain, it is not sufficient for the stain to affect all parts equally, as, for example, in the case of eosin, but rather it is essential that while all parts of the tissues are stained, the nucleus should stain more readily than the other parts. With borax carmine this is obtained by over-staining and then washing out the excess stain by acid alcohol, a process called differentiation. In this way a generally pink preparation is obtained in which the grouping of the nuclei can easily be seen, as they remain a dark carmine. Figure 11 shows a simpler case, where Chlorazol Black E dissolved in methyl alcohol has been used as a general stain for the mould *Penicillium*. Here there is no need to over-stain—in fact it is difficult to do so; the stain simply colours the nuclei more readily than the cytoplasm and so the extra process of differentiation is avoided.

It follows from the two cases I have illustrated that it is possible, by differentiation in the case of borax carmine, and by under-staining in the case of Chlorazol Black E, to stain the nuclei only and leave the rest of the tissue unstained. This leads on naturally to those cases where a stain picks out a particular tissue and leaves the rest unstained. Figure 16 provides an excellent example of the selective action of a stain. It shows the elastic tissues in the body wall of the stalked barnacle *Lepas* stained with Chlorazol Black E. In this case the specimen was stained for a short time—just a few minutes—and the elastic fibres stained black almost at once, before the rest of the tissues showed any appreciable staining. In many specific stains, however—in fact, in the majority—the stain affects only one particular tissue or one type of cell inclusion, so that the time that the section is left in the stain is of little importance. Thus mucicarmine is said to be specific for mucous cells, and orceïn for elastic fibres.

Once the idea of a specific stain was established, it was clear that a valuable effect could be obtained by double staining. Thus the Lignin Pink already mentioned is specific for lignified cells. On adding it, therefore, to Chlorazol Black E, a single solution is obtained which, while staining all nuclei and cell walls black, stains the woody tissue a definite carmine (figure 7). The value of this solution is that it does not over-stain and requires no differentiation. A more difficult but even more striking result is shown in figure 8. This is a section of the kidney of a frog tadpole. It was stained first in Hickson Purple, which produced a bluish effect in all cells. Subsequent staining in Victoria Green has picked out the red blood cells, and only these cells, in a definite green.

One of the simplest double stains used in medical laboratories is that of haematoxylin and eosin. In this case the nuclei only are stained bluish-purple, by the haematoxylin, and the cytoplasm of the cells red, by the eosin.

Double staining naturally led to triple and even more complicated methods. Figures 2 and 3 illustrate multiple effects produced by various well-known methods. It must be said, however, that the complicated recipes sometimes put forward for multiple effects are probably often over-complicated. In one case, certainly, which happened in my experience, a senior zoologist got tired of following the elaborate ritual of Mallory's triple stain, use of which is shown in figure 12, and mixed his solutions together. He obtained a very satisfactory staining effect; it may not have been the orthodox series of colours, but it led to extremely valuable results.

Sometimes a single solution when used by itself will produce a variety of colours. Chlorazol Black E in ethyl alcohol, for example, will stain the chitin of a crustacean limb a dull greenish-grey, while the muscles are given a brownish tinge. A very pleasing effect of this metachromacy, as it is called, is shown in figure 9. This is a section of esparto grass (incidentally taken from a herbarium where it had been dried for many years) stained in Chlorazol Azurine; it shows the vivid red-blue double effect.

Quite early in the history of staining technique, methods were used by which it was sought to impregnate particular tissues, especially nervous material. It was soon found that nerve fibres and nerve cells will take up compounds of gold or silver, which by a subsequent treatment somewhat akin to photographic development can be converted into dark material, and so become visible by contrast with the surrounding colourless tissues (figure 5). Another example given is in figure 6, which shows the nerve endings on vertebrate striped muscle. A more marked effect is the Golgi preparation shown in figure 14, where the individual nerve cells stand out an intense black. While these impregnation methods are very interesting and valuable, it must be remembered that they are capricious; it cannot be predicted which cells, if any, in a block of tissue will produce an effect, and which will be unaffected by the treatment.

The development of *intra vitam* methods, by which living cells take up stain, has made great strides of recent years. Thus, neutral red or methylene blue can be used to pick out particular cells or parts of cells in living tissues. Originally, the difficulty was to fix the cells after they had been stained. Methods have now been devised by which this can be done, and figure 13 shows a very beautiful effect produced by staining the nerve cord of a marine worm with methylene blue and subsequently fixing the stain. The individual nerve fibres are stained a definite blue.

The modern trend of research upon staining is to use this method as a means of analysing the physiology of the cell rather than its anatomy. This is beyond the scope of this short article, but there is one more case which I must mention because it is functional-anatomical. J. R. Baker, of Oxford, showed that by injecting Chlorazol Black E into the body of a mouse, certain cells called histiocytes or macrophages, under the surface of the skin, selected the dye and packed themselves with it so that they appeared black in section (figure 4). This then not only distinguished the histiocytes anatomically, but demonstrated their phagocytic behaviour.

Oliver Heaviside (1850-1925)

It is a seemly thing to praise great men, and most fittingly we celebrate this year the centenary of the birth of Oliver Heaviside, who was born in London in 1850. Heaviside did not receive any systematic schooling in his early years. In 1870, we find him a telegraph operator at Newcastle-upon-Tyne. He never married, but lived with his parents, who had removed to Devonshire in 1889, until their deaths. He later lived in almost complete seclusion in various Devonshire towns. His was by no means a neglected genius; he was elected to the Royal Society at the age of forty-one.

Heaviside's services to the advancement of electrical science were many. He arrived at the concept of a distortion-free circuit in which, by properly adjusting its resistance, inductance, capacitance, and 'leakance,' signals which kept the same form could be propagated along a cable, although attenuated, thus preserving their intelligibility. This operational calculus is internationally used.

His great contribution to electrical science was contained in a series of articles which were published in *The Electrician*. In these articles he developed his theories of wave propagation. Among the important results which he achieved was the prediction of the existence in the upper atmosphere of an ionized layer. This was shown by Dr W. H. Eccles to have important consequences (on account of its different refracting power for wireless waves) in long-distance radio telegraphy and telephony, and Eccles, in 1911, gave to it the name of the Heaviside layer.

Multiple-beam interferometry

S. TOLANSKY

Multiple-beam interferometry offers a delicate method of detecting extremely small imperfections in surfaces. Since highly polished surfaces are becoming increasingly important in technology the method finds many applications, for example in measurements of hardness on a micro-scale by the indentation method, and in studies of the contours of cleavage faces and the nature of cuts made with fine cutting-wheels. The method has proved informative in studying the modes of vibration of electrically excited quartz crystals.

The various techniques of multiple-beam interferometry have now established themselves as methods for investigating the micro-topography [1] and micro-motions [2] of surfaces. In such investigations, it is necessary first to prepare the surface under examination so that it has a high optical reflectivity; it is then matched against a suitably silvered optical flat. If the optical conditions are correct, then, as a consequence of the multiple reflections of beams, very sharp interference fringes can be formed between the surfaces. These sharp fringes are in effect topographical micro-contour lines, and with a correct technique it is possible to measure height-changes on the surface which are as small as one-thousandth of a light wave, i.e. about 5 A. This quantity is less than many crystal lattice spacings, and in fact some cleavage lattice spacings have by this method now been measured with ordinary light waves. It is a characteristic of the techniques that surface details to be examined must not be very small in extension, and an area bounded by a square of side 0·004 mm is about the smallest region that can be accurately studied. The power of the technique lies essentially in the up-down directions, but, despite this restriction, many applications are possible, especially when it is combined with a medium-powered microscope.

It is the purpose of this article to illustrate some of the investigations now being conducted in the author's laboratory, using a variety of multiple-beam interference methods, all of which have been evolved there within recent years.

METALS

The work on metals is in three distinct fields, (*a*) surface finish, (*b*) hardness tests, and (*c*) slip bands.

When surface finish and polish are very high, sharp straight-line fringes are obtained, and, conversely, deviations from the straight line are a measure of the surface roughness. Fine-lapped finishes of metal surfaces are becoming increasingly important in precision technology, and in this field the multiple-beam technique has much to offer as a means of examination of surfaces. Figure 1 shows the fringes given by a typically well-polished stainless steel, the magnification in extension being × 300. The surface irregularities are obvious when it is recalled that, on moving from one fringe to its neighbour, the height has changed by half a light-wave, i.e. about $25 \cdot \times 10^{-6}$ cm.

Figure 2 shows fringes given by a very well polished stainless steel surface with a super-micro finish. In contrast, figure 3 shows the rugged nature of polished aluminium, which, being softer, abrades more easily. Figure 4 illustrates the contours given by rolled sheet steel (tin-plate basis metal), and the rolling grain is very clearly revealed [3]. All these interferograms can be quantitatively evaluated with little labour.

A widely used method for testing the hardness of metals is to make an indentation with a diamond pyramid under known load, and then to measure the superficial dimensions of the indent (Vickers hardness test). Such tests are now often carried out on a micro-scale, using quite small indents—often less than 10 microns across. It was evident that, when the diamond penetrates, the surrounding surface is almost certainly distorted, and such expected distortion-effects have now been studied by interferometry [4]. Figure 5 shows fringes revealing the beautifully symmetrical surface-distortions produced by such a micro-indentation made on a polished steel surface, and this throws light on the mechanism of penetration. Figure 6 shows what takes place when the load is increased. It will be observed that the metal heaps up opposite the sides of the square indentation, but is not greatly distorted in the directions of the diagonals.

When an indentation is made into a single crystal of tin [5], the striking asymmetrical pattern of figure 7 is obtained. The extended wing regions prove to be piled-up hillocks and the short-winged

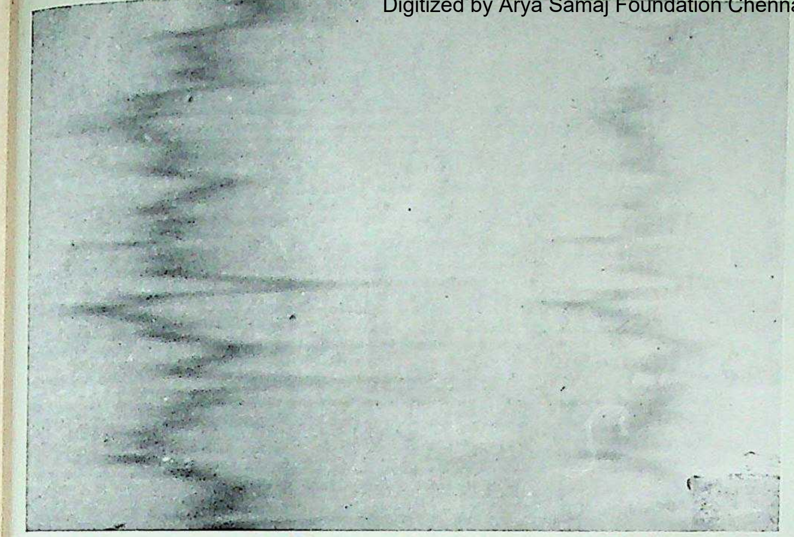

FIGURE 1 – *Fringes obtained in examination of well-polished sample of stainless steel by multiple-beam interferometry.* (× 300)

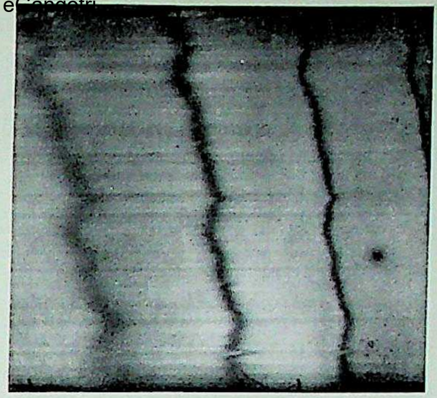

FIGURE 2 – *Fringes given by stainless steel with super-micro finish.* (× 120)

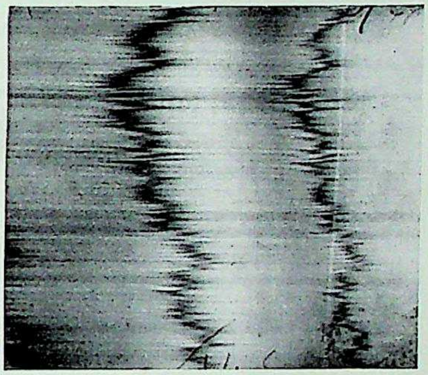

FIGURE 3 – *Relatively coarse contours of polished aluminium which, being relatively soft, is easily abraded.* (× 720)

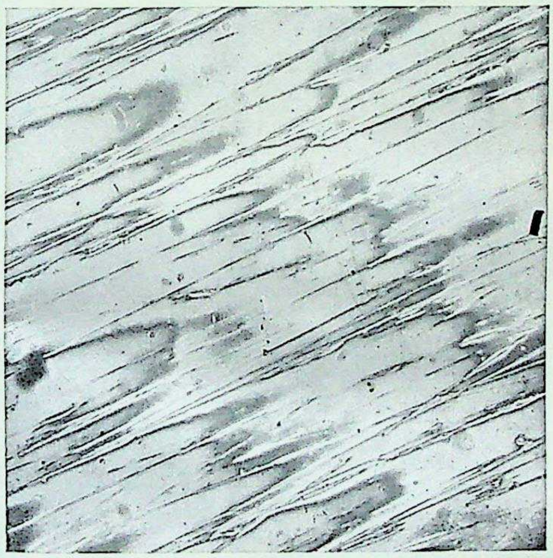

FIGURE 4 – *Fringes from rolled sheet steel.* (× 360)

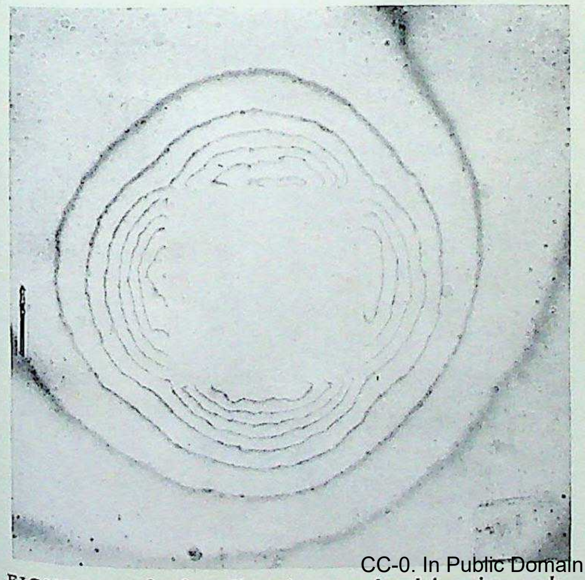

FIGURE 5 – *Surface distortions, produced in micro-scale hardness test, revealed by interferometry.* (× 120)

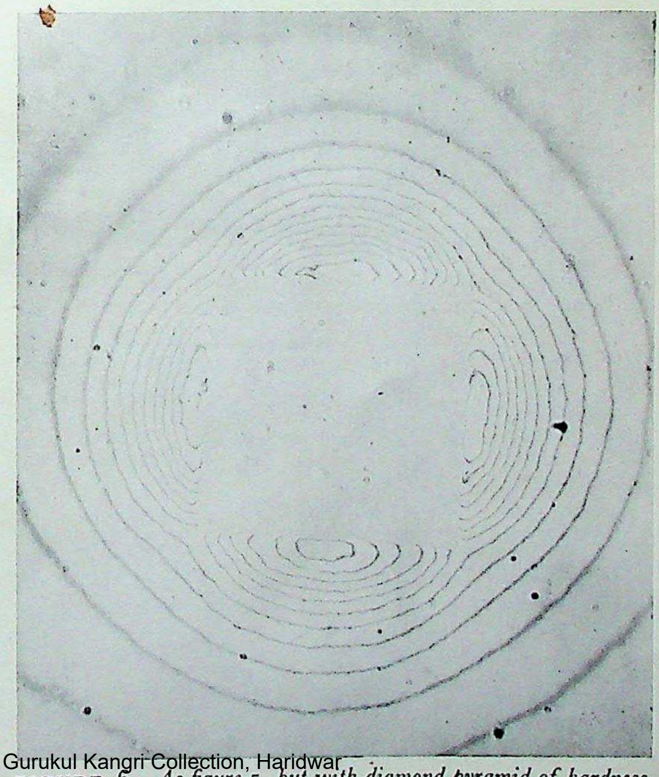

FIGURE 6 – *As figure 5, but with diamond pyramid of hardness test more heavily loaded.* (× 120)

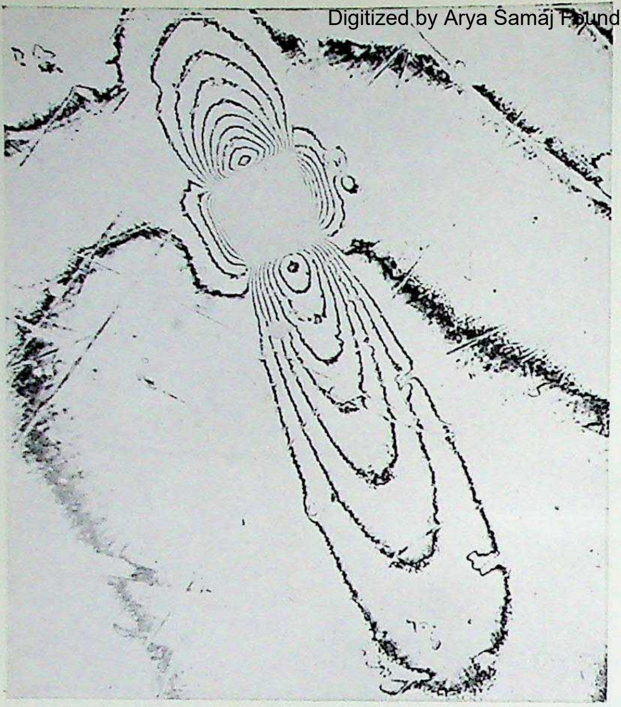

FIGURE 7 – *Asymmetrical contours produced when micro-scale hardness test is carried out on a single crystal of tin.* (× 120)

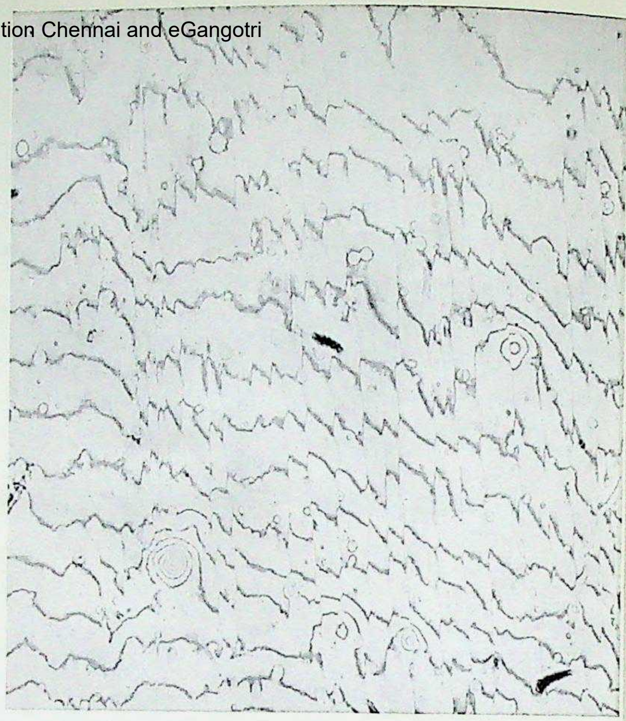

FIGURE 8 – *Slip bands produced by subjecting single crystal of aluminium to tension.* (× 250)

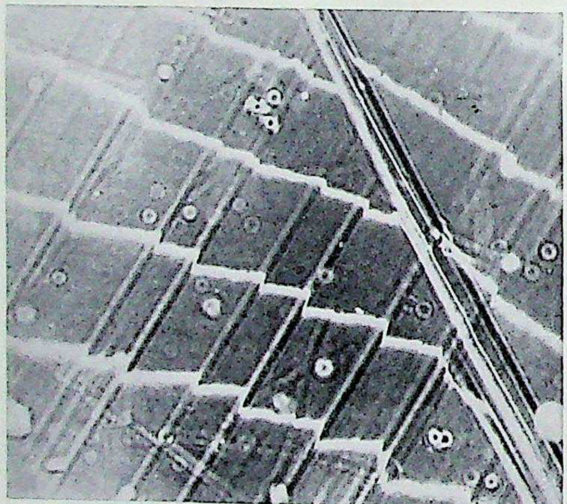

FIGURE 9 – *Picture of fringes superimposed on photomicrograph of slip lines produced in single crystal of tin.* (× 250)

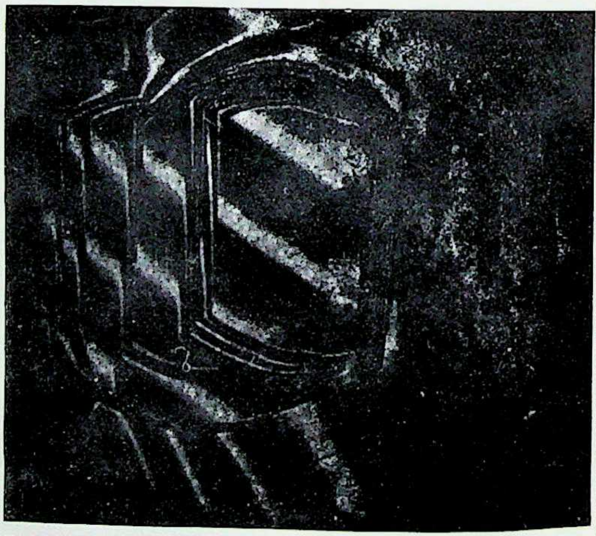

FIGURE 10 – *Contour pattern showing growth sheets on a crystal of beryl.* (× 50)

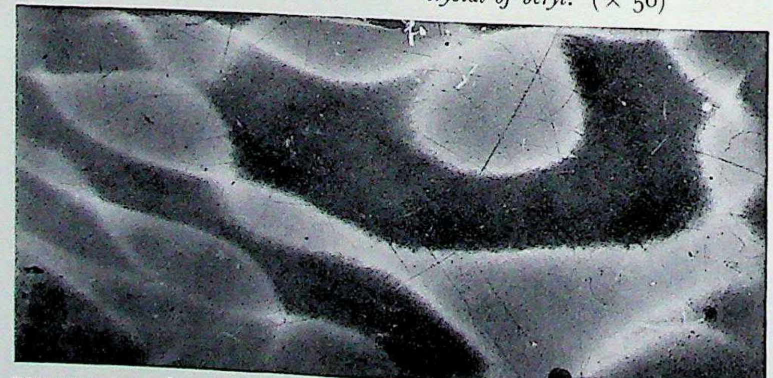

FIGURE 11 – *Interferometric pattern obtained from quartz crystal vibrating at high frequency, showing nodes and antinodes.* (× 10)

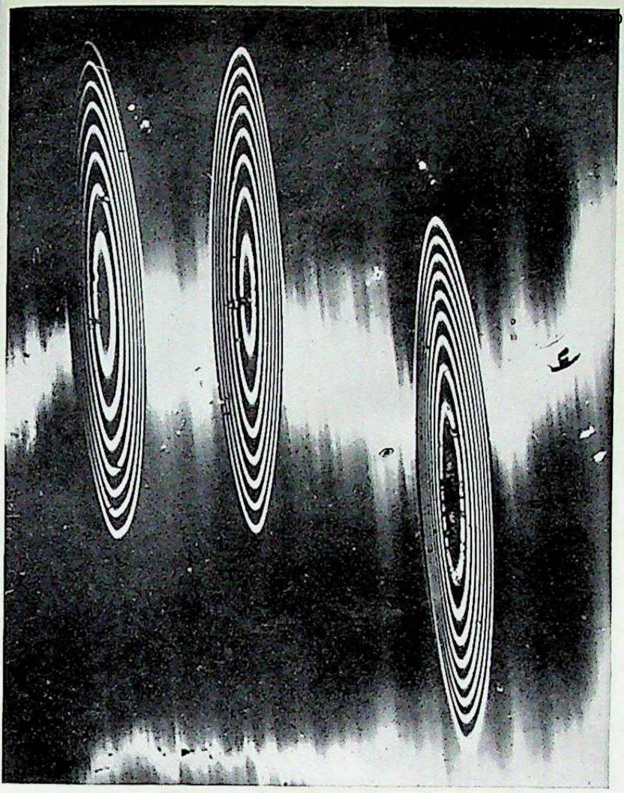

FIGURE 12 – *Fringes given by micro-abrasion formed by small rotating wheel bonded with diamond dust.* (× 120)

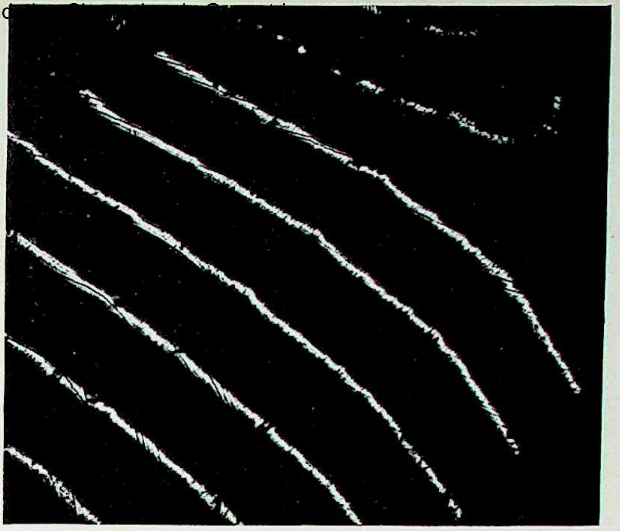

FIGURE 13 – *Fringes given by specially prepared diamond surface. Their sharpness indicates its exceptionally high polish.* (× 25)

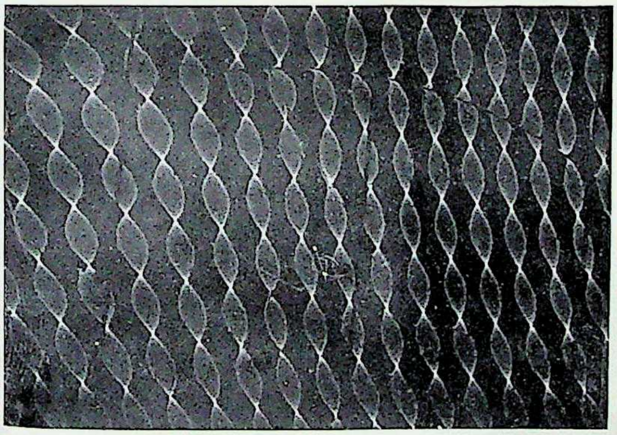

FIGURE 14 – *Fringes obtained with vibrating quartz crystal.* (× 10)

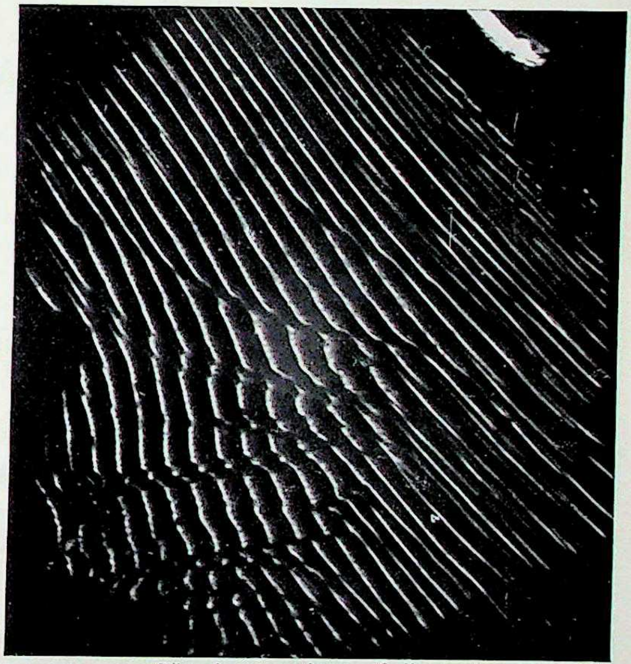

FIGURE 15 – *The cleavage planes of diamond are normally complex, but in this example the fringes show an exceptionally clean cleavage.* (× 120)

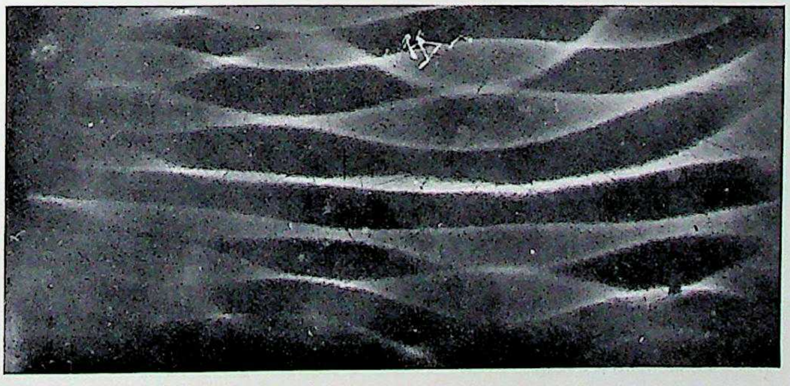

FIGURE 16 – *Fringes obtained with vibrating quartz crystal.* (× 10)

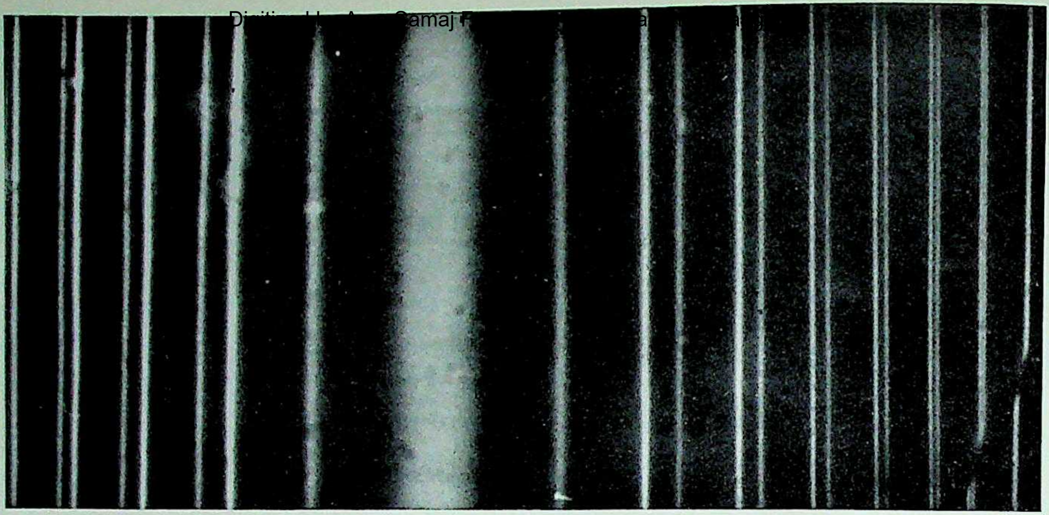

FIGURE 17 – *Fringes produced in a new type of fringe system obtained by means of a sharply curved piece of plane-parallel mica silvered on each side.* (× 10)

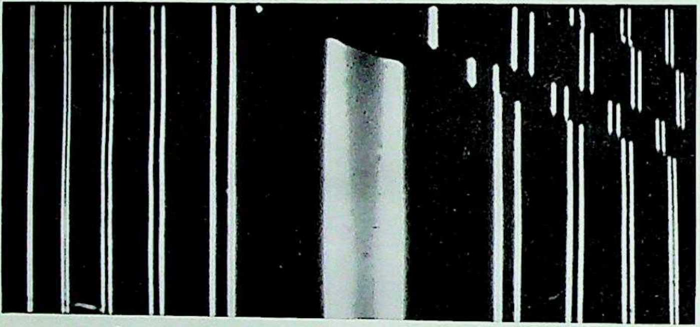

FIGURE 18 – *As above, but using a mica sheet having cleavage steps.* (× 10)

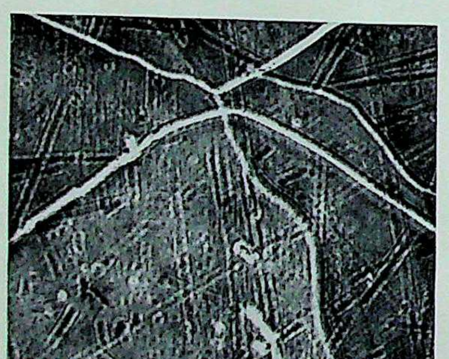

FIGURE 19 – *Fringes produced by two approximately parallel pieces of silvered mica. Brilliant colours result from very slight variations in the thickness of the mica.* (× 10)

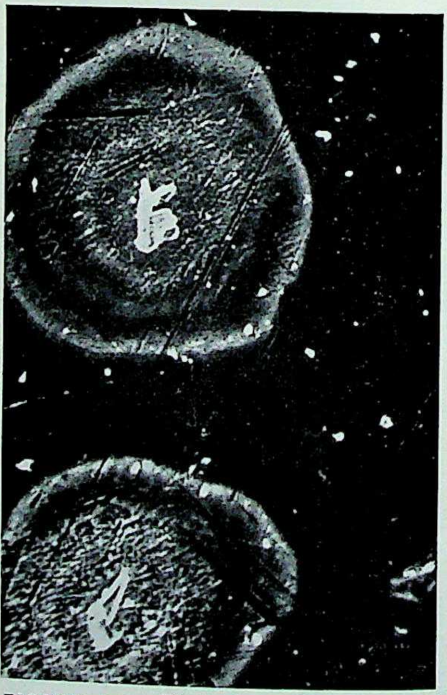

FIGURE 20 – *Illustration of the use of interferometry in revealing inclusions in mica which are normally invisible.* (× 25)

regions sunk-in valleys. It has been established that the effect is purely crystallographic, and is directly related to the direction of the crystal axes.

The work on slip bands [6] shows much promise. When metal crystals are strained, the familiar slip bands appear as a succession of close fine parallel lines, and it was evident that by running fringes across a metal surface which had first been polished and then subjected to a slight strain, information about the nature of the slip could be obtained. This has indeed turned out to be so. Figure 8 shows the fringes running across slip bands produced in single crystallites of aluminium when a slight tension has been applied. The step-like formation is rendered apparent, and exact numerical evaluation is an easy matter. Figure 9 shows a compound picture of fringes superimposed on an ordinary micrograph of slip lines produced on a single crystal of tin. Not only does this show the slip, but a marked difference between the aluminium and tin slip phenomena is very clearly rendered. The step-like displacements can be measured with considerable accuracy from such an inexpensive experiment.

CRYSTAL SURFACES

Work on natural crystal surfaces has been deliberately restricted to hard minerals (diamond, beryl, topaz, quartz) because such crystals are more likely to have retained their original surfaces. If the surface of such a crystal has a high natural polish it is not likely to have been weathered or abraded. The crystals examined were selected from considerable stocks for their perfection.

Valuable information on the mechanism of crystal growth has recently been obtained from beryl [7], on which highly complex interference contours have been observed. A typical example (offered here without explanation, owing to lack of space) is shown in figure 10. This reveals interesting growth sheets, which are repaying detailed study.

Much research is being conducted into diamonds, and on these the natural growth features, differential polish directions, and the contours of cleavage faces are all being studied. In particular, directional hardness is being examined by the interferometric analysis of a recently proposed abrasion test [8]. In this test a small rotating steel cutting-wheel, bonded with diamond dust, is applied to the surface with standard load, at a standard speed, for a given time, and a very shallow microscopic abrasion cut is formed. If the volume of this abrasion can be evaluated, then a measure of resistance to grinding and to polishing wear is obtainable. If the wheel be suitably oriented, the peculiar directional resistant properties of diamond can be studied. Precision interferometry is the only satisfactory way by which these volumes can be determined. Figure 12 shows fringes given by a number of such micro-abrasions [9]. Not only are the shapes and volumes determined, but the fringe definition within the cut shows that the abraded surface takes on an exceptionally high polish.

The ultimate surface finish attainable on a specially polished diamond has been found by interferometry to be surprisingly good. Figure 13 shows the best yet attained, and it will be recognized from the fringe sharpness that a very good optical surface has been obtained. This could be achieved only by repeated use of the fringes as a guide to progress in the polishing technique. High magnification studies reveal a grain structure which proves that there has been no flow during polishing.

Interferometric examination has shown that diamond cleavages are normally highly complex, but one individual fine specimen gave the fringes shown in figure 15. This has yielded to exact numerical interpretation.

OSCILLATING CRYSTALS

Recently [10] some spectacular results have been obtained by applying multiple-beam interferometry to the study of the mechanical oscillations of electrically excited quartz crystals. Crystals oscillating within a considerable frequency range (100,000–3,000,000 per second) have been successfully studied. In these experiments, sharp interference fringes are formed between the surface of a polished quartz crystal and an optical flat. When the crystal is set in oscillation by a suitable electrical circuit, some parts of the surface remain at rest (nodes) and other parts vibrate. A vibration amplitude of even a very small fraction of a light-wave produces a measurable change in separation between crystal and flat. As a result, at the moving regions the fringes broaden out, and thus the whole distribution of surface vibrations becomes clearly revealed, despite the small amplitudes and very high frequencies of the vibrations.

Figures 11, 14, and 16 are typical vibration pictures and obviously reveal a considerable amount of information. Thus, for instance, the distribution of nodes and antinodes is shown, and the amplitudes at the antinodes can be measured with great precision. Irregularities or crystal flaws reveal themselves by anomalies in the pattern. It has been established that some nodes are regions where the crystal is at rest to certainly within less than 50 A. A stroboscopic technique has also just been developed, in which a fraction of the oscillating voltage is tapped off from the crystal and used to excite the light source for producing the interference fringes. Since source and crystal vibrate at the same frequency, there results a 'frozen' picture of the fringes with the surface apparently at rest. By this means, not only can one measure the nodes, antinodes, and amplitudes, but in addition the instantaneous phases and directions of differential motions over the whole crystal are revealed: for the fringes do not broaden, but twist and bend round the regions which are instantaneously at the same level.

NEW INTERFEROMETRIC TECHNIQUES

A new type of fringe system has been developed [11], and while as yet the interest is purely academic, applications may possibly be evolved later. The mode of production of the system is as follows. A thin sheet of flexible plane-parallel material (e.g. mica) is silvered on both sides, and then bent cylindrically into a curvature of radius perhaps 5 cm. If this is illuminated with parallel monochromatic light a system of very sharp fringes appears, localized in a plane passing through the centre of curvature and perpendicular to the direction of incidence.

An example of such fringes is shown in figure 17. They are quite sharp, and are doubled, the components being mutually perpendicularly plane-polarized, because of the bi-refringent properties of the mica, which in fact produces several highly complex and interesting effects, all of which can be fully accounted for theoretically. If the mica has on it any cleavage steps, they appear within the pattern, as shown in figure 18, and this observation suggests a possible application, apart from the intrinsic optical interest of the system. It is quite easy to put down thin films and layers on to a sheet of mica or some other suitable flexible material, and, on bending, one obtains in effect the equivalent step thickness, representing the thickness of the film.

A new application of an old technique [12] has been the simple adaptation of the familiar principle of superposition, as applied to multiple-beam fringes of equal thickness (introduced many years ago by Fabry). This experiment is a method whereby the slight and normally invisible inclusions in mica, or the small changes of thickness at cleavage, can be revealed with clarity and precision by a simple device. A piece of mica is silvered and then cut in two, the two pieces being held together roughly, approximately parallel. The system is then illuminated with parallel white light, and as a result beautiful colour effects are seen. If the mica had been of perfectly uniform thickness, only a uniform tint would appear, but it is known that mica sheets have slight discontinuities in thickness, which are small cleavage steps varying in thickness and sometimes only a single molecular lattice high (20 A). Owing to the superposition principle, then, even if the mica is fairly thick, one obtains in effect interference over a path-difference represented by the small step, and thus the cleavage areas show coloured regions of uniform tint. One has, in fact, white light fringes of very high sensitivity, although using thick films. Figure 19 (in monotone) gives but a poor idea of the contrasts seen, for splendid colours appear to the eye. A cleavage step only one molecular lattice in height produces a bright change in colour.

Equally interesting is the sensitivity of the system for showing up 'invisible' inclusions within the mica. An example (which again suffers in monotone) is shown in figure 20. Here a small inclusion is revealed, and at the centre can be seen a small included foreign crystal, with a surrounding characteristic region, the contrast arising because of changes in the refractive index of the material.

CONCLUSION

Multiple-beam interference methods are opening up lines of investigation in several distinct fields. The enthusiasm and able participation of the research group in the physics laboratory at the Royal Holloway College are largely responsible.

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Some recent developments in rare-gas discharge lamps

J. N. ALDINGTON

Although the luminous effect produced by the discharge of electricity through gases at low pressures has been known for many years, and the Moore tube was in use as long ago as 1907, the further development of discharge tubes giving light of very high intensity is a quite recent achievement. Originally capable of giving only an intermittent light, very efficient 'gas arcs' have now been constructed which will continuously emit a brilliant white light.

INTRODUCTION

The luminous and other radiations produced by the electric discharge through rarefied air and other gases have been studied for many years. With the notable exception of the Moore tube, introduced in a commercial form in 1907, early gas-filled devices were of little or no value for purposes of general illumination. In view of its historical importance in relation to later developments, it is worth while to consider the Moore lamp in some detail. It consisted in general of a length of glass tubing of the order of 200 ft which was built up and processed *in situ*. The best results appear to have been obtained with tubing $1\frac{3}{4}$ inches in diameter; the colour and efficiency of the light depended on the gas in the tube. In some tubes, nitrogen was used and gave a soft golden light, and in others carbon dioxide, which gave a white light similar to that of the north sky.

Of the rare gases of the atmosphere only neon was found to yield a commercially useful light-source, and, largely owing to the work of Georges Claude, the neon tube for advertising and display purposes became the first rare-gas discharge lamp. It was first demonstrated in 1907, and was the forerunner of a whole range of high-voltage cold cathode discharge tubes which produced a variety of colours; the basic discharge in most cases, however, depended upon either neon or neon-argon and mercury vapour mixtures.

At a later date, fluorescent coatings on the inside of high-voltage discharge tubes were introduced, and the range of possible colours was greatly increased. These lamps in turn eventually led to the mains-voltage fluorescent lamp, which is becoming of considerable importance for general lighting purposes.

During the late nineteen-thirties, the author and his colleagues began a series of investigations involving the passage of heavy current discharges through the rare gases. By 1939, preliminary data had been obtained on discharges in which currents of many amperes were passed through boro-silicate glass tubes about $1\frac{1}{4}$ inches in diameter, containing neon, argon, and helium at comparatively low pressures.

It was found that the spectrum of the radiation was similar to that obtained with the Claude tubes, which generally worked at a current of only 25–50 milliamperes. The efficiency of light production was, however, low, owing to the fact that, although low-loss emissive electrodes were used, the voltage drop in the experimental lamps was only of the order of 30, the arc length being limited to about 20 cm. It was considered that the range of pressure and current conditions which ought to be investigated would require a different type of tube, and probably new circuit techniques, if the obvious possibilities were to be explored in even a preliminary manner. The object was to produce a concentrated-source gas-discharge lamp of high efficiency.

WORK ON CONDENSER DISCHARGES

Notwithstanding the lack of success of earlier attempts to produce a high-efficiency light source using the rare gases, it was felt that the possibility existed of producing a concentrated source provided that sufficient energy could be discharged through the gas. The capacitor discharge technique, for example, had been used successfully for many years for producing short-duration sparks in air. The substitution of a gas discharge tube for the air spark gap was an obvious development, and this method had been investigated by Edgerton and others.

In principle, the method was to charge a capacitor to a high voltage, and then to cause the lamp, which was permanently connected across the capacitor terminals, to become conductive by the production of an ionizing high-voltage high-frequency discharge on its walls. The conductive state would then build up to a maximum in a few microseconds, and the energy in the capacitor would discharge very rapidly through the lamp.

In early experimental work in the author's laboratories[1] using this technique, boro-silicate glass tubes of various lengths and diameters had a filling of a few mm of argon and a low pressure of mercury vapour. The object at this stage was to produce a very high current density discharge through low-pressure mercury vapour, but a spectroscopic examination of the radiation revealed that very little mercury vapour was present and that the discharge was being carried almost entirely by the rare gas.

It was therefore decided to investigate condenser discharges through the rare gases alone. Some interesting results were immediately obtained. It was found that as the energy discharged through the tube increased, the quality of the radiation changed, and spectrographs revealed that continuous radiation eventually developed at the highest current densities, and that the characteristic line spectrum of the gaseous element in the tube became less dominant (see figure 1). Eventually, tubes were produced in which an inner or guide tube was flanged at each end, but only one of the flanges was sealed into the outer tube. This device was adopted to allow expansion and movement of the inner tube under the shock-wave and temperature-rise which take place when the pulse discharge passes.

It was found that such tubes would carry considerable currents for very short periods of time; some typical data are given in the table below.

TABLE

Type	*Joule rating*	*Approx. lumen sec*	*Effective duration (microsec)*	*General use*
SF4	400	16,000	450	Scientific purposes
SF5	200	7,000	350	
SF6	100	3,000	200	

It was observed during the course of the work on this type of discharge that the arc did not completely fill the bore of the tubing (see figure 3, which shows a 200-joule discharge through a xenon-filled tube). Such photographs made it possible to measure the approximate width of arc, from which it was calculated that the average current density in the discharge was of the order of at least 1000 amperes per square centimetre.

Observations of this kind, together with measurements of the luminous efficiency of the discharge, indicated that the development of continuous radiation from the flash-discharge tube coincided with the development of relatively high efficiency. Careful measurements of the total flux from the SF4 tube, taken in conjunction with the energy discharged from the capacitor, showed that efficiencies of the order of 40 lumens per watt were possible in the xenon-filled tube, and about 30 l/W in the krypton-filled tube. In each case the colour of the radiation was white, and the distribution of spectral energy was not dissimilar to that of daylight, although there was a predominance of energy at the blue end of the spectrum over and above that present in daylight. Eventually a range of some ten types of tube was produced, and many uses have been found for these repeating flash-tubes, not only of the earlier linear form but also in more compact forms in which the discharge tube proper is wound into a helix of the type shown in figure 2.

The development of a highly efficient white-light source of intermittent character stimulated work on the production of a continuously burning rare-gas light-source of daylight quality and high efficiency, and eventually in 1947 the successful production of the gas arc was announced.

THE GAS ARC

The term 'gas arc' has been applied by the author to rare-gas discharge lamps operated under arc conditions which cause them to emit radiation of daylight quality. The radiation from the gas arc is characterized by an intense continuum extending from the ultra-violet through the visible region into the infra-red. It had been observed previously by the author and his colleagues that, while the low-pressure discharge through argon produced a bluish radiation of low intensity and efficiency, at higher pressures and with very high current densities argon could be excited to produce an intense white light of high efficiency. By comparison with the results obtained in the flash tube, the possibilities with krypton and xenon appeared even more favourable, and it was decided to investigate their behaviour over a range of pressures and current densities. In essence, the problem was to determine whether with available

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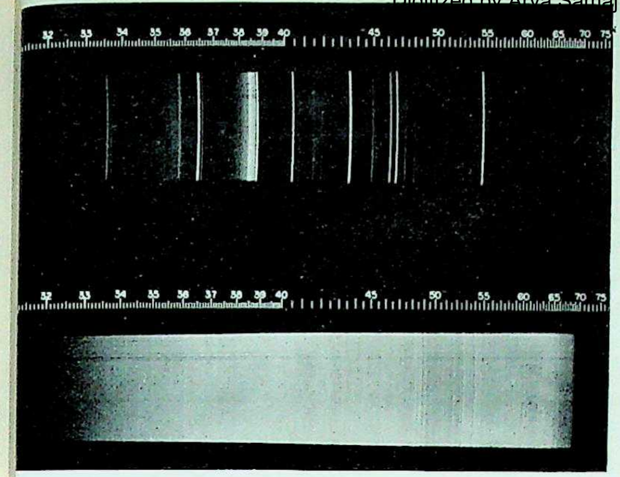

32 33 34 35 36 37 38 39 40 45 50 55 60 65 70 75
32 33 34 35 36 37 38 39 40 45 50 55 60 65 70 75

FIGURE 1 – (a) *Low-current discharge through krypton.* (b) *High-current discharge through krypton.*

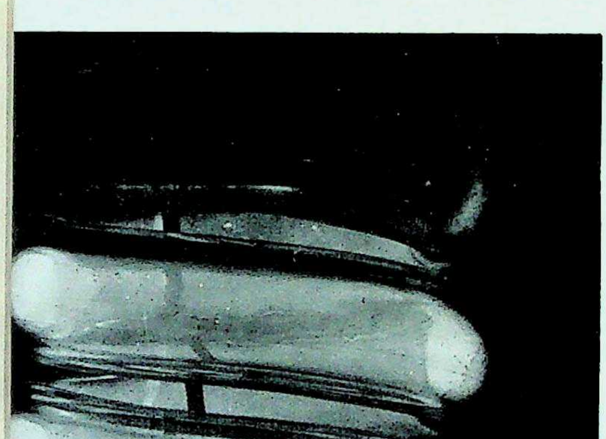


FIGURE 2 – *Helix of compact type of flash-discharge tube.*

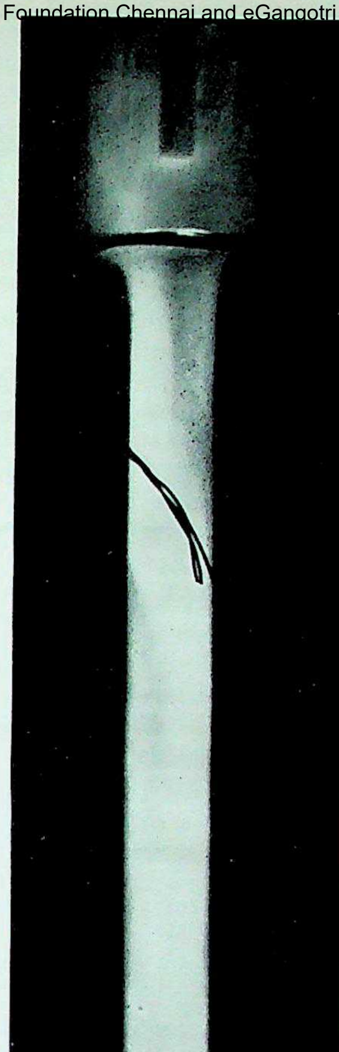


FIGURE 3 – 200-*Joule discharge through xenon-filled tube.*

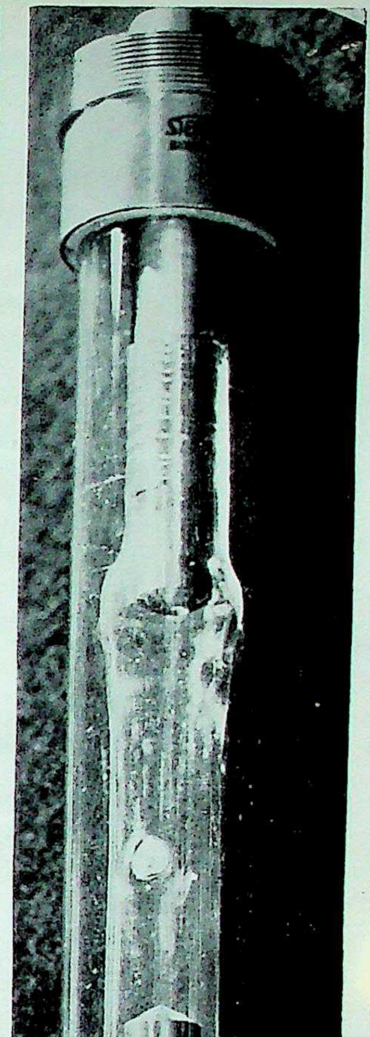


FIGURE 4 – *Complete gas arc in water jacket.*

materials it was possible to excite the rare gases, either singly or in mixtures, to such an extent that a continuous background spectrum was obtained, and secondly to determine whether under such conditions a practical lamp with a reasonably high efficiency would result.

In considering the development of any discharge tube in which a particular gas has to be hermetically sealed there are a number of obvious but important factors of which it is necessary to take account. These factors include the temperature which will be attained by the walls of the containing vessel, the temperature reached by the electrodes when the discharge is passing, the physical and chemical stability of the electrodes, and the material of the containing vessel exposed to the discharge. The ideal to be pursued is obviously a discharge lamp with an envelope consisting of a transparent refractory substance which will remain completely unchanged under the influence of the discharge; electrodes which suffer little or no sputter or evaporation during life; and a gas-filling which emits its full light output of daylight quality, and at high efficiency, immediately the lamp is switched into circuit.

It was found in the earlier work, and as shown in figure 3, that a constricted discharge occurred in krypton and xenon at quite low pressures. The effect is related to the high atomic weights and low mobilities of these elements. Such a constricted discharge tends to be very mobile, and is easily influenced by convection currents and electrical fields. It was therefore considered necessary for the practical attainment of a suitable discharge that the arc itself should be closely confined, and that convection currents set up in the gas should be restricted by the design of the envelope.

Such considerations suggested the use of a lamp of tubular form and of comparatively high loading. The general considerations outlined above made it clear that the only practicable material for the containing vessel would be quartz. Eventually, for a loading of 5 kW a quartz tube of about 12 mm bore, and with 6·5 cm between the electrodes, was chosen. It was necessary to cool the quartz tube in a stream of running water, and the completed gas arc is shown in figure 4.

The electrodes consisted of polished rods of tungsten containing 5 per cent. of thoria, the ends of the rods being tapered so that the arc was centred on the conical electrode tips. They were designed to fill the inside of the quartz tube closely, and at the ends remote from the arc-space they terminated in molybdenum sealing foils. During the construction of the lamp these foils were sealed *in vacuo* between the outer quartz tube and an inner quartz member, in a manner developed previously for the production of mercury-vapour arc lamps of high current-density.

The gas arc is essentially a high-current, low-voltage device. With a loading of 5 kW the current is of the order of 80 amperes and the arc drop between the electrodes of the order of 65 volts.

In parallel with this work on gas arc lamps of tubular form, experimental work has also been carried out on air-cooled gas arc lamps made from quartz and filled with xenon, similar to certain high-pressure mercury vapour lamps. If the distance between the electrodes is made quite short—of the order of 15 mm—it is possible to obtain an arc brightness of the order of 25,000 candles per square centimetre with a loading of 3 kW.

PROPERTIES OF THE GAS ARC

The water-cooled xenon-filled gas arc with a loading of 5 kW has an efficiency of about 30 l/W. A similar efficiency has been obtained with short arc-length air-cooled forms, and efficiencies as high as 40 l/W have been obtained with experimental linear forms of air-cooled lamp, designed in such a way that the arc voltage was of the order of 100.

The gas arc has a positive volt-ampere characteristic, but it is desirable to operate it in a similar way to other electric discharge lamps, namely in series with a current-limiting device, such as a resistance for direct currents or a reactance for alternating currents. When the lamp is in operation, the current can be varied over a wide range, and an important characteristic is the fact that, with change in arc current, there is only a second-order change in the colour of the radiation.

Compared with other light sources the gas arc has the following characteristics:

1. Excellent colour (similar to that of daylight).
2. Comparatively cool radiation (owing to the water-cooling).
3. Immediate attainment of full light output.
4. Considerable concentration of the light source (the water-cooled 5 kW gas arc has an average brightness of 5000 candles per square centimetre).

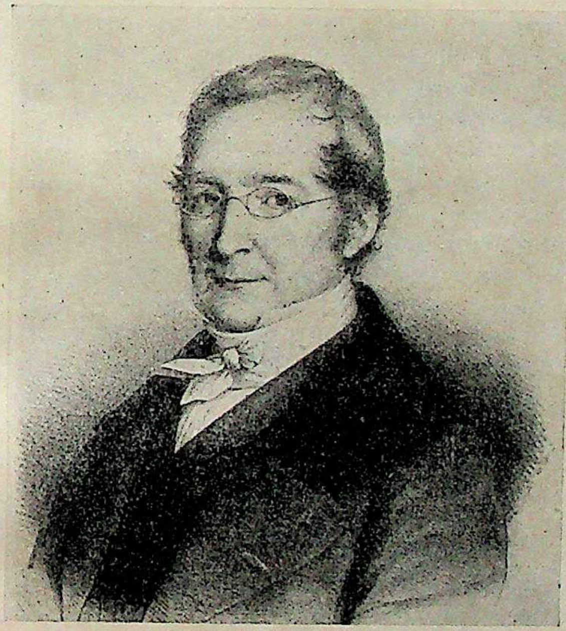
Of these properties, perhaps the most important is the fact that in the gas arc we have a light source which can be switched on and off at will, and in which full light output of daylight quality is immediately attained.

Gay-Lussac (1778-1850) as chemist

K. R. WEBB

The early development of chemistry owed much to a spirited and productive competition between the chemists of France and Britain. Among the many distinguished men of the time Gay-Lussac, who died one hundred years ago, stands very high. Davy, indeed, his great British contemporary, said that he would place Gay-Lussac 'at the head of the living chemists of France,' a place to which his formulation of the law of gaseous combining volumes would alone give him a strong claim. He also did much work on physics.

One day in the early twenties of last century a visitor to Paris, calling at one of the foremost chemical laboratories of Europe, might have beheld a middle-aged bespectacled Frenchman of generally grave demeanour engaged in waltzing round the laboratory with a good-looking but rather bewildered young German. The elder was Joseph Louis Gay-Lussac, the greatest living French chemist; the younger was Justus von Liebig, later to be professor at Giessen and Munich and a founder of the nineteenth-century German chemical school. Gay-Lussac was celebrating, in the poetry of motion, a successful investigation by Liebig into the nature of the fulminates, carried out under his direcion [1].



Gay-Lussac

Joseph Louis Gay-Lussac was born at St. Léonard-le-Noblat, about fourteen miles from Limoges, on 6th December, 1778, the son of a legal official who was also a local landowner [2]. To the family name of Gay had been added that of the village, Lussac, where the property was situated. Because of the distracted state of France during his early years, the boy was educated at home by a cleric, the Abbé Bourdeix, until the time when the ecclesiastics were expelled, and it was not until November, 1794, that he was able to go to Paris to begin formal study for the admission examination to the *École Polytechnique*. During this period he was a high-spirited youth, and in his later, more sedate, days he astonished his friends by tales of boyish escapades, in which he was usually the leader, and which generally had some such object as raiding an orchard [3].

Even in 1795 conditions in the capital were none too tranquil, and the story is told of young Gay-Lussac, armed with a large sabre, accompanying his landlady into Paris from the rural outskirts where they lived, when she took in for sale a cartload of milk each night. On the return journey in the early morning, her escort lay in the bottom of the cart, studying geometry or algebra.

Gay-Lussac's studies were fruitful, and on 27th December, 1797, he was admitted to the *École Polytechnique* after a brilliant performance at the examination, and having successfully completed the course there—during which he found time to give mathematics lessons to augment the state grant of 60 francs a month—he left the school on 22nd November, 1800.

He was already marked out for fame, and having assisted Fourcroy and acted as demonstrator to Berthollet, who observed his quickness and intelligence, Gay-Lussac was transferred to Berthollet's private laboratory at Arcueil, there to begin his research career with investigations on the physical properties of gases and vapours. In 1802 he published his first paper, on the thermal expansion of these bodies. Other physical studies occupied his attention at this period, involving

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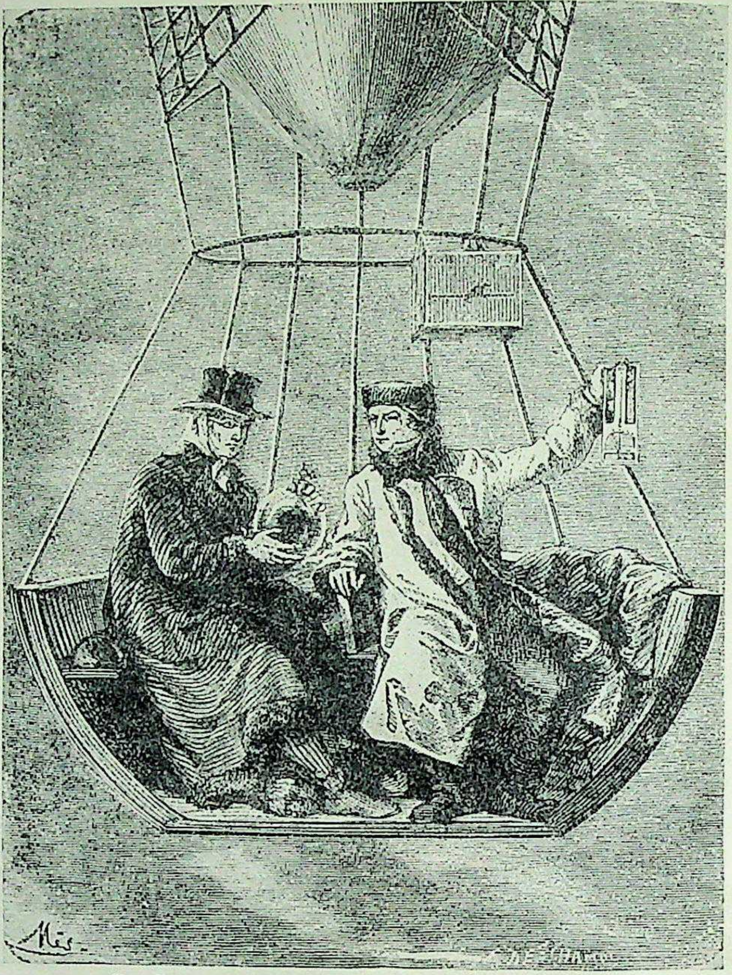
work on vapour pressures, thermometry, hygrometry, eudiometry, and the measurement of capillary effects, in which he seems to have been a pioneer in the use of the cathetometer.

During 1804, in conjunction with Biot, he engaged in aerostatic adventures of a spectacular sort, though with strictly scientific intent. The purpose was to discover whether magnetic forces persisted above the earth's surface. In the first ascent they found no diminution up to 4000 metres—the best the balloon could do with both men on board—and in a later ascent, on 16th September, 1804, made by Gay-Lussac alone to over 7000 metres (the highest attained up to that time), he confirmed the earlier findings and brought down specimens of air for analysis. During this ascent, having reached 7016 metres and wishing to ascend still higher if possible, Gay-Lussac jettisoned a few objects to lighten the balloon. A shepherdess was amazed to see a white wooden chair come hurtling down into some bushes, but the realist peasants who heard her story were at a loss to correlate its suggested celestial origin with its evidently crude workmanship [4].



Gay-Lussac and Biot making their balloon ascent

On 12th March, 1805, Gay-Lussac set out from Paris with Alexander von Humboldt, recently returned from his famous American travels, for a scientific expedition into Italy and Germany. They arrived in Rome early in July, and here, in the house of Wilhelm von Humboldt, the Prussian minister, the youthful *savant* enjoyed the company of various notables in the artistic and scientific worlds, and, having a laboratory at his disposal, discovered the presence of fluorides as well as phosphates in the bones of fish. Later, the travellers moved on to Naples, where Vesuvius, previously quiescent for some time, suddenly reasserted itself, so that, in the words of one of his companions, Gay-Lussac had the happiness to experience one of the most memorable earthquakes ever known in that region. On the return journey, pauses were made at Florence, Bologna, and Milan, where they visited Volta—whom they had some difficulty in finding, as he lived modestly in obscurity. Arriving during November in Berlin, Gay-Lussac stayed there as von Humboldt's guest throughout the winter, and finally returned to Paris in the spring of 1806. On 8th December, 1806, he was elected a member of the *Institut de France*, in place of Brisson, the physicist and natural historian.

In 1807, Gay-Lussac became one of the first members of a select scientific society—the *Société d'Arcueil*—founded by his early patron, Berthollet. In the second volume of its *Mémoires* (that for 1808) occurs a paper, read on 31st December, 1808, announcing for the first time the outlines of Gay-Lussac's law of gaseous combining volumes, one of the foundation stones of early chemical theory.

About this time Gay-Lussac began his fruitful collaboration with Louis Jacques Thenard (1777–1857) [5], of which more will be said later. Also in 1808 he married Joséphine Rogeot, whom he had first met as an assistant in a linen draper's shop in Paris. This girl of 17 was, he observed, engaged in reading a treatise on chemistry during her spare moments. It turned out that Joséphine's education had been disturbed by the aftermath of the Revolution, so Gay-Lussac had her interrupted schooling completed and they then married. It was an ideal match, although at the time Joseph had no position of importance. This was, however, just round the corner, for soon afterwards he became professor of physics at the Sorbonne, and on 31st March, 1809, professor of practical chemistry in the *École Polytechnique*, and full professor on Fourcroy's death in 1810.

Gay-Lussac and Thenard had first met as fellow-students at the *École Polytechnique* in 1798; in 1808–9 they began work together, using a gigantic electric battery provided for their use by Napoleon himself, in an endeavour to surpass the brilliant discovery of the alkali metals by Davy in 1807. Before the battery had been assembled, however, the two Frenchmen discovered an alternative, and at that time more efficient, means of decomposing the alkalis, viz. their reduction in a molten state by white-hot iron. Using potassium so prepared they reduced boric acid, a preliminary note being read on 21st June, 1808. Such pioneer work was not unaccompanied by dangers, and Gay-Lussac was seriously injured by an explosion on 3rd June, 1808, involving potassium, in which he almost lost his sight and from the effects of which his eyes permanently suffered. By the end of 1808 the new element, boron, had been pretty well characterized; it should be said that Davy also did much independent work in this field.

In addition to their use of the alkali metals in this way, Gay-Lussac and Thenard also studied their oxidation and prepared their higher oxides, as well as those of barium and calcium [5].

About this time, too, occurred the famous controversy between Gay-Lussac and Thenard and Davy concerning the nature of chlorine, then called oxymuriatic acid and believed to contain oxygen. Davy's experiments showed conclusively that the gas contained no detectable oxygen, and that in all its reactions it behaved as an element. The Frenchmen, adhering to Lavoisier's view that muriatic (hydrochloric) acid must contain oxygen as the acidifying principle, considered that chlorine, a product of its oxidation, must of necessity also contain oxygen. Eventually, the correctness of Davy's views became clear, and so there vanished from chemistry the outmoded 'oxygen theory' of acids [6].

In 1812, iodine, the second of the halogen elements to be isolated, was discovered by Courtois. Soon after the publication of his discovery, both Davy and Gay-Lussac were independently engaged on an investigation of the substance and its derivatives. The result of this work was the establishment of iodine as an element, and by August, 1814, Gay-Lussac was able to present to the *Académie des Sciences* his completed 'Researches on Iodine.' He contributed also to early fluorine chemistry, for in 1809, in collaboration with Thenard, he first prepared a reasonably pure specimen of concentrated aqueous hydrofluoric acid. The crude material had been obtained by Scheele in 1771 [7].

In 1815, two very important pieces of work were done. Already, in 1811, Gay-Lussac and Thenard had introduced potassium chlorate as an oxidizing agent in quantitative organic analysis. This substance proving rather violent, Gay-Lussac, in 1815, substituted for it the more moderate copper oxide, especially for the analysis of nitrogenous substances. Very soon, Döbereiner applied copper oxide universally in place of the chlorate, with great success. Also in 1815, Gay-Lussac discovered cyanogen, the first compound radical to be isolated. Prussian blue was described as early as 1704; from it Scheele in 1782 had obtained, by distillation with sulphuric acid, an aqueous solution with a 'peculiar smell and taste'(!). This was named prussic acid by Lavoisier, de Morveau, Berthollet, and Fourcroy in 1787 [7]. In 1811, Gay-Lussac obtained the anhydrous substance by distilling mercuric cyanide with concentrated hydrochloric acid, and, in 1815, he isolated cyanogen itself by the thermal decomposition of mercuric cyanide. He showed the general chemical analogy between cyanogen and chlorine and iodine.

The next year, 1816, saw the publication of his paper on the oxides of nitrogen, important for its account of the analysis of nitrogen dioxide. Some years earlier he had determined the composition of nitric oxide by burning metallic potassium in the gas. Three years later, in collaboration with Welter, he discovered and investigated aqueous dithionic acid.

About this time, Gay-Lussac began to be increasingly occupied in the development or modification of processes of importance in chemical technology. In 1806 he had been made a member of the consultative committee of arts and manufactures. In 1818, he became superintendent of the government powder factory; in 1829, chief assayer at the Mint; and in 1832, professor of general chemistry at the Museum of Natural History, whereupon he resigned from his chair of physics at the Sorbonne.

In 1821, Gay-Lussac showed that wood is made non-inflammable by impregnating it with various inorganic salts, such as borax or ammonium phosphate, which can be readily prepared in quantity. The Gay-Lussac tower for the absorption and conservation of nitrous gases in the lead chamber sulphuric acid process was introduced in 1827, the result of a sudden flash of inspiration on Gay-Lussac's part; indeed, it has been said that the idea presented itself to him overnight, and that, with the aid of an assistant called Lacroix, he had shown its practicability on a small scale by early next morning [2].

Gay-Lussac's great services to analytical chemistry were of fundamental importance, since he must be regarded as the chief founder of the volumetric method. In 1806, Decroisilles had substituted measurements of volumes for those of weights in the determination of alkali by acid; however, Gay-Lussac, while preserving the principle, greatly simplified the operations involved by the invention of his burette (a pouring instrument, different from the modern instrument with clip or tap, introduced later by Mohr), and applied the method not only to acid-alkali titrations, but also to the determination of chlorine in bleaching powder using arsenious acid solution (1824, 1835), and later to the determination of silver by a standard solution of sodium chloride (published fully during the eighteen-thirties).

Two other pieces of work are perhaps deserving of mention; they were his discovery (1829) that an oxalate results from the interaction of fused alkali with wood, a discovery afterwards put to practical use in the manufacture of oxalic acid, and his investigation of the volatile products evolved from *aqua regia* (1848); this was his last published work.

Gay-Lussac entertained what were, at the time, remarkably advanced and far-sighted ideas about the state of salts in solution, ideas which became a part of chemical theory only towards the end of the nineteenth century with the development of the work of van't Hoff and Arrhenius; indeed, he must be considered as one of the founders of modern physical chemistry. These ideas appeared in his article on cohesion, published in 1839.

Gay-Lussac's character and temperament have been sketched by various contemporaries. Very early, Berthollet said to him, 'Young man, your destiny is to make discoveries.' Davy, about 1813, contributed a telling thumb-nail sketch: 'Gay-Lussac was quick, lively, ingenious, and profound, with great activity of mind, and great facility of manipulation. I should place him at the head of the living chemists of France' [8]. This, from Davy, was praise indeed. Another British tribute came from the toxicologist Sir Robert Christison, who attended Gay-Lussac's lectures in 1820 and was much impressed by his handsome and amiable appearance and gentle though firm voice. Christison describes his lectures as 'a superlative specimen of continuous unassailable experimental reasoning' [9].

Another estimate (by Ferguson, not a contemporary) is perhaps more detached if rather less sympathetic: 'Gay-Lussac was reticent, patient, persevering, accurate to punctiliousness, perhaps a little cold and reserved, and not unaware of his great ability. But he was also bold and energetic, not only in his work, but equally so in defence and support of his friends. The endurance he exhibited under the laboratory accidents which befell him showed the power of will with which he could face the prospect of becoming blind, and useless for the prosecution of the science which was his very life' [10].

On 1st January, 1850, Gay-Lussac was taken ill at Lussac, whither he frequently retired in his later years and where he had a house with a laboratory and library. After about two months, he was moved to Paris during a brief respite in his sufferings, and there he died of a heart disease on 9th May, 1850, in his seventy-second year [2]. As long as the principles of chemical science are taught, Gay-Lussac will never be forgotten; with Lavoisier, Dalton, Berzelius, and a handful of others, he is an immortal of chemistry.

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Book reviews

TREATISE ON ZOOLOGY

Traité de Zoologie (Anatomie, Systématique, Biologie), *publié sous la direction de Pierre-P. Grassé. Tome VI. Onychophores, Tardigrades, Arthropodes (généralités), Trilobitomorphes, Chélicérates. Pp.* 979. *Tome IX. Insectes (Paléontologie, Géonémie, Insectes inférieurs et Coléoptères) Pp.* 1117. *Tome XV. Oiseaux. Pp.* 1164. *Masson et Cie., Paris.* 1949–50. 5000 *francs,* 4500 *francs, and* 6000 *francs respectively.*

The first volume of this series to appear set a very high standard, in both production and matter. These latest additions maintain or surpass it. They remain as well produced and printed as their forerunner, enhanced by splendid colour plates, particularly in Volume VI, and clear, well-printed photographs in Volume XV. Unfortunately the increase in excellence has brought with it an inevitable increase in price. It is, however, gratifying to find the volumes appearing so rapidly; for certain sections of such a work must fall out of date in a very few years. The early volumes of a series stretched over a long period would therefore have deficiencies before the completion of the whole work.

Once again the sections are each written by acknowledged experts in their subjects. The result is an all-embracing work covering most of the possible aspects of the anatomy and life-histories of the groups, combined with valuable discussions of their inter-relationships and past history. This is particularly useful in the general discussion of the Arthropod phylum in Volume VI, and in the consideration of the collection of groups with doubtful affinities which makes up the rest of the volume. The theory of continental drift is rightly introduced in the section on the palaeontology and distribution of insects, and a thorough account of the various theories of the origin of bird flight is also given.

It is in the very completeness of these volumes that their failing, if indeed there is any, must lie. To give a full history of the orders, both ancient and modern, with a full description of their behaviour, embryology, physiology, ecology, and economic importance, would be a monumental task. Inevitably, parts of this scheme must be condensed. Pride of place is given, not unnaturally, to the anatomy of the animals. Other sections take their place according to their importance in a general scheme of zoology and the amount of knowledge available on the subject. A good balance is generally kept. Volume XV is an excellent example. Here a detailed and up-to-date description of avian experimental embryology is included with a review of the vast accumulation of work on the behaviour of birds and their reproductive cycles. In addition, a concise account of bird flight, the mechanics of the bird skeleton in general, and all the morphological and historical detail of the group, are given. Sometimes the non-morphological sections are almost too concise, as, for example, in the sections on bird migration, the insect cuticle, and stridulation in grasshoppers. It must be admitted, however, that their brevity lies laudably in a rigid selection of the best of the most modern work, the references to which form an adequate basis for deeper study. The importance of the sections depends, of course, upon the viewpoint of the reader.

As standard works for general reference these volumes take their place in the front rank, unblemished by their occasional, but often rather delightful, misprints, and sometimes puzzling internal chapter references.

J. D. CARTHY

PHYSIOLOGY OF VISION

Recent Advances in the Physiology of Vision, *by Hamilton Hartridge. Pp.* 412. *J. and A. Churchill Limited, London.* 1950. 25*s. net.*

As the author remarks in the preface, five important books have been published in Britain in the past five years dealing with this topic. Professor Hartridge, director of the vision research unit of the Medical Research Council, adds to these a review of recently published work, comments on the theories of its authors, and sometimes offers his own alternative interpretations. The book is divided into eight main chapters, each dealing generally with a different function of the eye, e.g. investigations of retinal function, the perception of shape and size, the perception of colour, and theories of colour vision. Other chapters are devoted to the neurology of vision, properties of the structures of the eye, the appreciation of light and colour, and some basic properties of vision.

In describing experiments and their results Professor Hartridge writes with all his usual lucidity; when discussing theory, however, impartiality demands that all points of view should be mentioned. The treatment in this book occasionally tends to blur the general picture, since the theories (of colour vision, for example) are often quite numerous. One of the author's express purposes is to stimulate further research by pointing out gaps in our knowledge, and in this way the book will undoubtedly be very valuable to the research worker and specialist. It will be less so to the student, until he has some acquaintance with the subject.

The nature of many of the problems remaining to be solved suggests that striking progress in research would follow an intensive application of the delicate techniques now made available by advances in electronics and nuclear physics.

J. M. M. PINKERTON

CYTOLOGY

La Cellule: Principes de Cytologie générale et végétale, *by R.-J. Gautheret. Pp.* 404. *Albin Michel, Paris.* 1949. 960 *francs.*

This excellent book should be particularly valuable at the present time, when so many interesting researches on the cell are being made by investigators who have scarcely any background of general cytological knowledge. The whole field of cytology is covered without undue emphasis on any particular part. In this, the book is unique among modern textbooks of the subject. In a work of moderate size it is not possible to enter deeply into any particular aspect of the subject without upsetting the balance, and the author carefully avoids this pitfall. Not every specialist will approve of every section of the book. For instance, the explanation of phase-contrast microscopy is not quite satisfactory, and the description of the interphase nucleus will not find universal acceptance. In general, however, the information given is reliable, debatable points are handled judiciously, space is not wasted in the discussion of hypotheses, and the whole exposition is an admirable example of French logic and clarity.

Many cytologists have a primarily botanical or a primarily zoological outlook; many are either students of the nucleus or else concentrate on the cytoplasm. Professor Gautheret's wide outlook and level judgment serve well to draw together the apparently disconnected constituents of what should be a single science.

JOHN R. BAKER

SOIL SCIENCE

Soils, their Physics and Chemistry, *by A. N. Puri, with a foreword by Firman E. Bear. Pp. xv + 550, with line diagrams. Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1949. 56*s. net.*

Prospective readers of this book must not assume from its title that it is a textbook. It is an exhaustively detailed treatise mainly based upon the author's own research, and presents a new and independent approach to the chemical and mechanical processes of soils. As such, it is a timely contribution to the progress of soil science, and it may also prove to be the most notable world contribution yet made by Indian science. Dr Puri's own preface rejects the description of his book as a treatise, and insists that it is written for students. It is difficult to accept this, for his conceptions are unorthodox, and, although they simplify the problems of soil science for students, they must obtain general approval before they can be regarded as safe foundations for education.

No one could disagree with Dr Puri's contention that orthodox soil science is confusing, incomplete, and all too often indecisive. He pleads, with both eloquence and evidence, for simpler and more fundamental principles. If the best that our present principles can provide is soil analysis results which must be interpreted more or less empirically, is it not time to return to the beginning and reshape our ideas? Most younger soil scientists are increasingly conscious of these weaknesses, and they will find Dr Puri's attempt to unify the irreconcilables and close the gaps remarkably bold and stimulating.

His chemical approach to soils is they are all acids capable of forming salts; these salts are called 'saloids' and natural soils are mixtures of saloids of soil 'acidoids.' Their chemical behaviour follows ordinary stoichiometric laws. As saloids are salts of weak acids, they are considerably subject to hydrolysis; thus, dry regions will tend to have alkaline soils and areas of high rainfall acid soils. The author insists that soil investigations must be concentrated upon the exchangeable hydrogen of the soil acidoids. He rejects the conception of adsorption, particularly for the phosphate ion. He presents a purely chemical explanation for the nitrification of nitrites.

Whether all Dr Puri's simplifications will achieve eventual support remains to be seen. Many may feel that soil science, like medical science, must remain among the inexact sciences. It is, nevertheless, of the greatest importance that this book should be carefully studied by soil scientists.

D. P. HOPKINS

RICHARD WILLSTÄTTER

Richard Willstätter: "Aus meinem Leben." *Edited by Arthur Stoll. Pp.* 462, *with a coloured portrait and* 49 *illustrations. Verlag Chemie, Weinheim/Bergstrasse.* 1949. 28 DM.

When Richard Willstätter died in 1942, shortly before his seventieth birthday, one of the last great figures of organic chemistry in Germany had gone. It is an unbroken line of pioneers, leading from Justus von Liebig to his pupil A. von Kekulé, to Adolf von Baeyer, and to Emil Fischer and Richard Willstätter. Few belonging to Willstätter's generation are left; Willstätter's successor at the university of Munich, H. Wieland, is due to retire, and Hans Fischer, another of Munich's great organic chemists, is dead.

The memoirs of Willstätter, written for the most part in exile in Switzerland, have been carefully collected and edited by his faithful friend and assistant of many years, Arthur Stoll. His scientific work is treated merely as a sideline in this book, which is mainly a contribution to the cultural and scientific life of Europe. The distinguished career of Willstätter, which was begun in Munich under his great master, Adolf von Baeyer, led to the scientifically rich period at Zürich, and then to a few years in Berlin-Dahlem. It ended in 1924 when, once more in Munich—this time as Baeyer's successor—he voluntarily resigned, long before Hitler came to power, in protest against anti-Jewish discrimination. However, Willstätter continued his work on enzymes, with his faithful assistant Dr Margarete Rohdewald, until, in 1939, he found refuge in Switzerland from threatening and unbearable persecution.

This autobiography of a great scientist is written without bitterness, but with all the love of a good German for his country. Richard Willstätter, who was a Foreign Member of the Royal Society and a Nobel Laureate, will be remembered for his work on alkaloids, chlorophyll, anthocyanins, and enzymes when the nightmare names of his persecutors are long forgotten.

P. ROSBAUD

OCEANOGRAPHY

The Sea and its Mysteries, *by John S. Colman. Pp.* 285, *with various line drawings and half-tone illustrations. G. Bell and Sons Limited, London.* 1950. 12*s.* 6*d. net.*

The sea is a vast three-dimensional medium. The science of oceanography, of which it forms the subject-matter, is a composite of all the sciences from astronomy (through its connection with the tides) to bacteriology. Nowadays no one person can have detailed knowledge of more than a few of these sciences, and even the expert will in any case have either a physical or a biological outlook. It follows that any general account of the sea must reflect the major interests of the author. Mr Colman is a zoologist, as the reader of his book will soon discover, but he has produced an unusually well-balanced account of the sea. His initial chapters deal with the physics and chemistry, and while they naturally owe much to *The Oceans* by Sverdrup, Johnson, and Fleming, they also contain what is probably the first popular account of recent work on waves.

Mr Colman speaks with the authority of unusually wide experience when he comes to deal with marine biology. He has personally studied tropical plankton, worked on coral reefs of the Great Barrier of Australia and in the West Indies, has made important contributions to the study of intertidal zonation on both British and American shores, and has carried out deep-sea investigations in many latitudes. All this appears in his writing, which has a most refreshing—and in popular books a most unusual—air of first-hand knowledge. The book is illustrated with a series of excellent plates and many text figures. those dealing with deep-sea animals being particularly good. The reviewer considers this to be as good a book on the subject as could be written within its compass.

C. M. YONGE

CHEMICAL CALCULATIONS

Advanced Chemical Calculations, *by S. J. Smith. Pp.* 454. *Macmillan and Company Limited, London.* 1950. 17*s. net.*

This is intended to continue the author's 'Introductory Chemical Calculations' to intermediate and honours standard. Problems not lending themselves to comparatively easy mathematical treatment, or involving only substitution in formulae, are omitted. A very large number of examples, many from examination papers, with answers, will make the book useful to students and teachers. In some cases the text explains the methods, in others reference is made to books. Calculations in organic chemistry are included, but methods of deducing structure are not explained. Thermodynamics and electrochemistry form part of the syllabus in physical chemistry. The American nomenclature and symbols are used in thermodynamics but the European convention for electrode potential in electrochemistry. The symbol °A is used instead of the now common °K, and the faraday is denoted by φ instead of F (its value being taken as 96,540, which corresponds to the old atomic weight of silver, 107·93). The text is usually adequate, although the difficult question of liquid contact potential, which causes trouble with most students, is not very well done, and some cases in which it occurs are treated as though it were absent. Some minor inaccuracies can be corrected in future editions. There is confusion between $\overline{u}^2$ and $\overline{u^2}$ in kinetic theory. The curves in figure 3, page 47, show maxima and minima of vapour pressure rather than deviations, and C_A, etc., on page 147 are not 'specific heats.' In the deduction of freezing point depression from the lowering of vapour pressure it is much better to deal with the ice curve than with the solution curve, as is done on page 325, since the good student will notice that no formula for the change of vapour pressure of a solution with temperature has been found. This book will be useful, and all teachers will agree that the working of numerical exercises is necessary in arriving at a real understanding of physical chemistry.

J. R. PARTINGTON

PLANT PATHOLOGY

Plant Pathology, *by Sir Edwin Butler and S. G. Jones, D.Sc. Pp. xii + 979, with 435 half-tones and line drawings. Macmillan and Company Limited, London.* 1949. 63*s. net.*

One of the few men having the breadth of experience and vision needed to scan the whole field of plant pathology was Sir Edwin Butler. In his earlier work, *Fungi and Disease in Plants*, published in India in 1918, a general section on fungal morphology, nutrition, and pathogenesis was followed by descriptions of diseases of oriental crop plants. The present volume was first undertaken as a revision of the 1918 text but developed into a completely new book, in which the emphasis on tropical plant diseases was transferred to those of importance in Britain.

Before his death in 1943, Sir Edwin had almost completed the general section of the work, which is distinguished by his assured handling of the relations between host and fungus, and of the influence of environment on parasitism. This section is concluded by a general survey of the disorders of plants caused by viruses and by nutritional deficiencies.

For the remaining two-thirds of the volume Dr S. G. Jones chooses the plan of marshalling specific diseases by crops, not by the systematic position of the pathogens. The diseases selected for description include not only those of cereals, pasture crops, roots, vegetables, and fruit, but of ornamentals and forest trees. The examples range over a wide geographic field, but prominence is given to the diseases common in Britain.

In a subject now so dissected by specialization it may well be that this book will represent a last attempt to produce a comprehensive text. By its very nature a synthesis of this type must have numerous faults in detail, but the whole remains an outstanding performance, demanding a place in every laboratory in which plant disease is studied. Its long-awaited publication crowns the great achievement of the senior author in shaping the course of plant pathology throughout the British Commonwealth and Empire.

R. W. MARSH

AERIAL MAPPING

Aerial Mapping and Photogrammetry, *by Lyle G. Trorey. Pp.* 178, *with numerous half-tones and line diagrams. Cambridge University Press, London.* 1950. 25*s. net.*

Dr Trorey has had a great deal of experience in the field of surveying from air photographs, and in consequence this most useful book is practical in its approach to the subject-matter. It is almost entirely restricted to work at topographical scales, and includes many descriptions and diagrams, particularly of the graphical methods employed in map-making. The modern automatic plotting machines are not entirely neglected, for the chapter dealing with Multiplex equipment is both informative and well written. Apparatus other than the Multiplex using the space intersection methods is, however, dealt with only very sketchily.

Information is given about the techniques used in Canada and not generally practised in this country. Of particular interest is that section dealing with oblique photographs.

The publication of such a volume is particularly appropriate now that so many changes in the methods of land surveying are being made. One is left, however, with the feeling that some considerable period elapsed between the completion of the original manuscript and the date of publication, for part of the information given relates to methods and apparatus that are no longer considered to be economically employable, at least from the commercial point of view of mapping from air photographs.

E. A. MISKIN

HIGH POLYMERS

High Polymeric Chemistry, *by W. S. Penn. Pp.* 487, *with various line and half-tone illustrations. Chapman and Hall Limited, London.* 1949. 36*s. net.*

This book on high polymers is one of several now appearing which aim at bridging the gap between technological treatises on plastics and physico-chemical monographs on long molecules. The Mark and Mark-Raff volumes in the Interscience series were the first general textbooks on the subject, and, more recently, Bawn and Ritchie in Britain have both written further general accounts of polymer chemistry.

Mr Penn's book comes closest to those of Ritchie and Mark-Raff in content, and is a qualitative account of the general and organic chemistry of high polymers. Good books can be written from this standpoint, as Ritchie has shown, but this is not one of them. Its chief and most curious characteristic is that it is up to date in its content yet out of date in its treatment. It certainly covers a wide range of polymer subjects, many of which, such as "cold" GR–S synthetic rubber, have only recently become of topical interest, but the treatment throughout is singularly old-fashioned, if not woolly. From the references, the book seems to have been written in the 1945–7 period, yet the ideas in it are more appropriate to 1940. The range of references, both academic and industrial, is extremely wide, and this perhaps explains the flavour of the book, because little attempt has been made to prune out many ancient, irrelevant, and discredited theories and experiments. This applies especially to the early and important chapters on mechanisms and methods, both of which are very disappointing. The book contains many wild generalizations which cumulatively are very irritating. I do not feel that it succeeds in its object.

R. F. TUCKETT

Some books received

(*Note.* Mention of a book on this page does not preclude subsequent review.)

AGRICULTURE

Agricultural Periodicals of the British Isles 1681–1900, and their Location, *Compiled by F. A. Buttress. Pp.* 16. *School of Agriculture, University of Cambridge.* 1950. 2*s. net.*

ASTRONAUTICS

Interplanetary Flight, *by A. C. Clarke. Pp.* 164, *with numerous half-tone and line illustrations. Temple Press Limited, London.* 1950. 8*s.* 6*d. net.*

ASTRONOMY

Astronomy of Stellar Energy and Decay, *by Martin Johnson. Pp.* 216, *with line and half-tone illustrations. Faber and Faber Limited, London.* 1950. 16*s. net.*

BIOLOGY

Amino Acids and Proteins—Cold Spring Harbor Symposia on Quantitative Biology. *Pp.* 217, *with numerous half-tone and line illustrations. The Biological Laboratory, Cold Spring Harbor, U.S.A.* 1950. $7 *net.*

Biochemical Aspects of Genetics, *edited by R. T. Williams. Pp.* 60. *Cambridge University Press, London.* 1950. 6*s. net.*

Biological Oxidation of Aromatic Rings —Biochemical Society Symposia No. 5. *Pp.* 96, *with various tables and line diagrams. Cambridge University Press, London.* 1950. 8*s. net.*

Wild Animals in Captivity, *by H. Hediger. Pp.* 207, *with numerous line drawings and half-tone illustrations. Butterworth's Scientific Publications, London.* 1950. 35*s. net.*

Mineral Nutrition in Plants and Animals, *by Frank A. Gilbert. Pp.* 131, *with numerous half-tone illustrations. Hutchinson's Scientific and Technical Publications, London.* 1950. 12*s.* 6*d. net.*

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